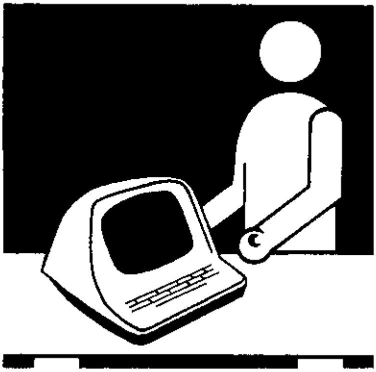
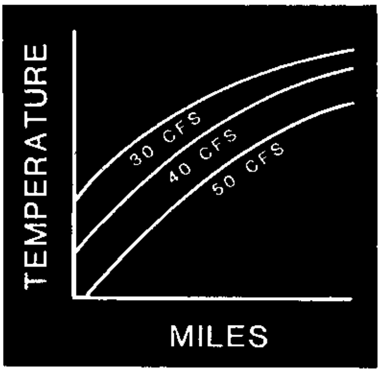


INSTREAM WATER TEMPERATURE MODEL

COOPERATIVE
INSTREAM FLOW
SERVICE GROUP

INSTREAM FLOW INFORMATION PAPER: NO. 16

FWS/OBS-84/15
SEPTEMBER 1984



Cooperating Agencies:

Fish and Wildlife Service
Soil Conservation Service

ERRATA FOR INSTREAM FLOW INFORMATION PAPER 16

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish. Wildl. Serv. FWS/OBS-85/15. v.p.

The following errors were noted after printing. We sincerely apologize for any inconvenience this may have caused you.

Page	Par#	Revision
I-4	4	tim >> time
I-6	Replace 4	The stream temperature model software is available only for IBM and compatible microcomputers. It may be obtained as part of the IF312 class taught at CSU on a regular basis, or from our distribution contractor. For information on the CSU classes, contact: Midcontinent Ecological Science Center Courses Office of Conference Services Colorado State University Fort Collins, CO 80523 (303) 491-7767 For other distribution, at a small cost, contact: Johnson Controls World Services, Inc. Technology Service Division P.O. Box 270308 Ft. Collins, CO 80525-3400 (303) 226-9413
I-7	1	respresentative >> representative
I-12	4	1.81 >> 0.64; 2.12 >> 0.58
II-7	1	site latitude [delete 'for day i']
II-18	4	riparian vegetation >> riparian shade is a function
II-19	fig	A_t >> A_r
II-32	Table	The default value of a_1 actually used in the program is -0.0014, not -0.00088 as shown in the row labeled ALL in Table II.3.
II-32	eqn.	T_{ax} = maximum (not average) afternoon air temperature
II-37	(66)	Vegetation emissivity should be 0.9238 (decimal)
II-41	(75)	Equilibrium depth is assumed to be 1 meter.
II-42	(77)	add '+ H_f'
II-48	line 1	notional >> notational
II-80	1	variable unknown >> variable, unknown
II-82 & II-83	last 1	The models do NOT have an option for English units. Only the Stand-Alone Shade and Stream Segment models contain English units.

II-86	last	Vegetation emissivity should be 0.9238 (decimal).
III-6 to III-60		This section is essentially obselete, though parts may be of specialized interest.
III-10	Add to Top	The HP-34C program is not supported by the FWS.
III-14	Add to Top	The HP-41C program is not supported by the FWS.
III-40	mid	<u>State on</u> >> <u>Station</u>
III-57	all	This BASIC program has been completely replaced by SSTEMP, the Stream Segment Temperature Model and its companions, SSSOLAR and SSSHADE.
III-66	#3	Manning's n-value (dimensionless) or travel time (seconds/kilometer).
III-70	3	The Stream Identification must be consistently named on each stream (see Table III-14 for an example). If your stream changes names, use a hyphenated combination.
III-71	all	It is perhaps more useful to replace the ordinal 'Character positions' 1-8 with actual column positions 17-24.
III-71	#2	Stream Geometry >> Hydrology data
III-71	#4	Hydrology node >> Hydrology data
III-71	#5	ditto
III-71	#5	Option 1 - add 'Do not use too close below an S node. Option 4 - add 'Model will perform self-initialization for zero flow H nodes by default. Option 6 - add 'Equilibrium temperatures may be used at H nodes also, but model may predict negative water temperatures.'
III-71	#7-8	Hydrology Data Temperature transfer code - used by the TRNSPT program to indicate temperatures to be transferred from a diversion to an H or P node downstream. (See temperature transfer option documentation).
III-77	mid	Record 3, Field 13 is now Table X: Job Control Record 3, Field 14 is now Table XI: Average and Maximum Temperature Results, If Field 14 is set to '"', the Average and Maximum Temperature Results will be created with titles in quotes for spreadsheet applications. Field 15-20 are reserved
III-78	mid	Record 3, Field 78 Shade Data File present Field 79 Global Shade Model to be used
III-78	mid	Record 4, Field 17-24, always zero.

III-78	bot	Record 4, Field 33-40, enter number of shade nodes
III-79	top	Record 4, Fields 65-72 and 73-80 can always be 0
III-79	last	Record 6, Field 57-64, always first time period. Field 65-72, always last time period. These are due to bug in program.
III-80	top	Record 6, Field 73-80 may always be 0.
III-80		Record 7, Fields 1-8, 9-16, 17-24 are EFA, EFB, and EFC, respectively, with defaults of 40, 15, and 0. Refer to equation II(70) on page II-38. The EFC factor is the coefficient for the square root of the wind speed, not mentioned in the manual. If you change one, you must enter all values.
III-80		Record 7, Fields 33-40, 41-48, 49-56, and 57-64 are a0, a1, a2, and a3, respectively, with defaults of 6.64, -.0014, -5.27, and 4.86. See page II-32. If you change one, you must enter all values.
III-81	Bot	Records 10 and 11, all fields must be left-justified. Record 10, Field 33-48 is not used at present time.
III-82	top	delete Record 11, Field 17-32, duplicate from previous page.
III-83	tab	Record 2, Field 25-32. If using a daily time step, make # days = 1, otherwise make 2 regardless of length of time step.
III-83	tab	Record 2, Field 33-40, see page II-13.
III-83	tab	Record 2, Field 41-48, see page II-14.
III-85	tab	Record 3, Field 49-56 is optional. If not supplied, it will be calculated. If supplied (see note at end of table) it will be used to calibrate all years.
III-86	top	Record 2, Field 33-80 >> 34-80
III-88	mid	Record 3, Field 33-80 >> 34-80
III-88	bot	Record 4, Fields 17-72 are not required for B, T, or E nodes.
III-88	bot	Record 4, Field 41-48 and 49-56, needed only if you are not using a shade file.
III-88	bot	Record 4, Field 57-64 defaults to mean annual air temperature.
III-88	bot	Record 4, Field 65-72 defaults to 1.65.
III-89	mid	Record 2, Field 33-80 >> 34-80
III-90	mid	ditto

III-91 tab	Record 3, Should be as follows:

(Record)	(Field)	(Description)
3	1-16	Stream name
3	17	Node type
3	18	Local output flag
3	19	Unused
3	20-21	Regression model instructions
3	22	Local shade model linkage flag
3	23-24	Temperature transfer code (See SNTEMP.DOC for temperature transfer option description)
3	25-32	Distance from system endpoint (km)
3	34-80	Remarks describing node

III-91 tab	Record 4, Field 25-32, see page III-69 for R nodes
III-91 tab	Record 4, Field 33-40, defaults to mean annual air temperature.
III-91 tab	Record 4, Field 41-48 need not be supplied at a "flow through" type reservoir.
III-91 1	B, T and E nodes are not included in the shade data file.
III-92 mid	Record 3, Field 33-80 >> 34-80
III-92 mid	Record 5, Fields 9-16 and 17-24 are reversed.
III-94 fig	It is useful to add to figure the comments: From skeleton to geometry, add C nodes study , add O nodes hydrology, add Q V K D P R From geometry to shade, subtract T, B, and E.
III-97 2	Change 'mean annual air temperature' to 'mean air temperature'.
III-100 top	Skeleton file is not used at present.
III-103 mid	Change ground temperature to mean annual air temperature.
III-115 III.21	This file format has been completely revised to be a random access file. See internal program documentation for file format.
IV-1 to IV-71	This section is essentially obselete, though parts may be of specialized interest.
IV-58 mid	This BASIC program has been completely revised.
IV-70 mid	Though magnetic tape version is available, the only supported version will be available on diskette. See note and ordering information for page I-6 above.

FWS/OBS-84/15
September 1984

INSTREAM WATER TEMPERATURE MODEL

Instream Flow Information Paper 16

by

Fred D. Theurer[1]
U.S. Soil Conservation Service
on detail to
Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Fort Collins, Colorado 80526-2899

Kenneth A. Voos[2]
Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Fort Collins, Colorado 80526-2899

and

William J. Miller[1]
Graduate Research Assistant
Colorado State University
Fort Collins, CO 80523

[1]Current Address - Hydroecosystem Research Unit, P.O. Box E, Fort Collins, CO 80522

[2]Current Address - Woodward-Clyde Consultants, One Walnut Creek Center, 100 Pringle Avenue, Walnut Creek, CA 94596

Western Energy and Land Use Team
Division of Biological Services
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

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PREFACE

This paper has four parts, each designed for a different target group. Therefore, each part is designed to stand alone, even though some readers may belong to more than one target group.

Part I. Applications. This part is written as an overview for managers and first-time potential users. It is designed to: (1) explain the objective and scope of the model; (2) provide guidance regarding basic data sources; (3) provide guidance on the use of the different solution techniques available; and (4) provide examples that illustrate the use of the model.

Part II. Physical Processes and Math Models. This part is written for the hydrologist or hydraulic engineer responsible for the physical modeling results. The fundamental principles involved and the math models used to describe them are explained in detail.

Part III. User's Manual. This part is written for the technician who will actually be doing the calculations. It describes the various solution techniques available, their input requirements, and their scope of program coverage. At the moment, none of the solution techniques solve the entire model, not even the mainframe computer program. However, most model components can be solved by one or more of the solution techniques.

Part IV. Software Support Documentation. This part is written for the ADP/engineering staff responsible for supporting each solution technique(s). It provides a comprehensive program description for each solution technique. This part also provides, for each solution technique, information useful for purposes of maintainence, modification, transportability, and linkage to other related models.

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CONTENTS (continued)

CONTENTS (continued)

CONTENTS (concluded)

FIGURES

FIGURES (concluded)

TABLES

TABLES (continued)

TABLES (concluded)

ACKNOWLEDGEMENTS

Any technical manuscript of this size and complexity obviously builds upon the work of others. Some mention of the more prominent seems to be appropriate. First, to recognize key personnel, and second, to admit that any undertaking of this size is not a "lone ranger" operation, but is an extension of the effort of other people--and other institutions.

Two Polish scientists, Drs. Andrezej K. Kraszewski and Witold F. Krajewski, on sabbatical from Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland, and Institute of Environmental Engineering, Technical University of Warsaw, Warsaw, Poland, respectively, worked with Dr. William J. Grenney at Utah State University, Logan, Utah. Together, they provided an important nexus that led to an analytic solution of the heat transport equation. This, in turn, made both the network solution and diurnal fluctuation calculations feasible.

John M. Bartholow, of the Instream Flow and Aquatic Systems Group, U.S. Fish and Wildlife Service, contributed the BASIC program version to this paper.

The Tennessee Valley Authority's Water Resources Research Laboratory and the Department of Energy's heat flux relationships were an important necessary basis for minimizing the input parameters previously required of other similar models for heat flux relationships.

The U.S. Forest Service provided a rudimentary shade model that led to an analytic basis for evaluating both the topographic and riparian vegetation shade.

The American Water Resources Association graciously allowed the repeat of the Tucannon River article as an example in this paper.

The U.S. Soil Conservation Service provided the funding and personnel for the model development and subsequent coding of the solution techniques.

And, finally, recognition is required of the work of the U. S. Fish and Wildlife Service personnel at the Western Energy and Land Use Team who labored many hours preparing and editing the text, tables, equations, and figures. Ms. Madeline Sieverin typed the manuscript, Ms. Jennifer Shoemaker prepared the illustrations, and Ms. Cathy Short edited the manuscript.

FWS/OBS-84/15
SEPTEMBER 1984

INSTREAM WATER TEMPERATURE MODEL
Part I. Applications

Fish and Wildlife Service

U.S. Department of the Interior

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PART I. APPLICATIONS

INTRODUCTION

The Instream Flow and Aquatic Systems Group (IFASG), in cooperation with the U.S. Soil Conservation Service (SCS) and the U.S. Fish and Wildlife Service (FWS), has developed this model to predict instream water temperatures based on either historical or synthetic hydrological, meteorological, and stream geometry conditions. The model is applicable to any size watershed or river basin with a stream network of any stream order and complexity. The model incorporates several features, including:

(1) A heat transport model that predicts the average mean daily water temperature and diurnal fluctuations in water temperature as functions of stream distance;

(2) A heat flux model that predicts the energy balance between the water and its surrounding environment;

(3) A solar model that predict the solar radiation that penetrates the water as a function of latitude, tim of year, and meteorological conditions;

(4) A shade model that predicts the solar radiation-weighted shading resulting from both topography and riparian vegetation;

(5) Meteorological corrections that predict changes in air temperature, relative humidity, and atmospheric pressure, as functions of a change in elevation; and

(6) Regression aids that smooth and/or fill in missing water temperature data at headwater and internal validation/calibration locations.

This paper describes these, and subsidiary, features, such as statistical aids and guidance regarding basic data sources, and describes how to use the model in ungaged watersheds.

The instream water temperature model was designed to predict the average daily temperature and diurnal fluctuations in water temperatures throughout a stream system network. It mostly uses readily available meterorological and hydrological data. Stream geometry information also is necessary, but often is collected as a part of previous or concurrent hydrologic studies. However, the model does not require the collection of new field data (e.g., stream temperature) over some period of time before the temperature regime of a stream system can be predicted. The use of previously collected data may help to calibrate the model, but is not necessary for most applications.

Meteorologic data required by the model consist of certain solar radiation coefficients, air temperature, relative humidity, sunshine ratio, and wind speed. These data often are available from published climatological and related data but generally require extrapolation to a point in the basin. The model includes features to transpose meteorology data from a single known point in the basin throughout the stream network.

Solar radiation is entirely modeled as a function of the latitude of the stream basin, time of the year, and prevailing meteorological conditions.

Shading, resulting from both topographic features and riparian vegetation, is modeled as a function of latitude, time, basin topographic characteristics, and riparian vegetation parameters.

Hydrological data required by the model consist of discharge or flow data throughout the stream system and initial water temperatures at the beginning points. The hydrological data needed, either the discharge, initial temperature, or both, can be developed from synthetic hydrological procedures or from known or assumed reservoir operation procedures, where applicable. The model includes regression techniques to smooth and/or complete water temperature data at points of at least some known water temperature.

Stream geometry information needed consists of the stream system network (mainstem and tributaries), stream widths, stream gradients, shading parameters, and hydraulic retardence. Data on all but the shading parameters are normally collected as part of a hydrological study.

The instream water temperature model can be conceptualized as three general parts: (1) input preprocessing; (2) heat flux relationships; and (3) a heat transport equation. Input preprocessing includes the preliminary input generation, such as the adiabatic meteorological corrections, solar radiation, and regression models. The heat flux relationships deal with the heat sources and thermal processes involved in the exchange or generation of heat, including back radiation from the water. The heat transport equation describes the downstream movement of heat energy in the water and the actual exchange of heat energy between the water and its surrounding physical environment.

Instream models differ from lake models because the downstream water movement tends to mix the water. This turbulent mixing is assumed to evenly distribute the temperature both vertically and transversely and, therefore, is the basis for using a constant water temperature throughout a given cross section at any given instant. The purpose of the transport model is to predict the longitudinal temperature variation. While the temperature at a specific cross section may be constant at any given time, a downstream differential is expected and predicted.

The turbulent mixing, leading to a homogeneous distribution of temperature throughout a given cross section, simplifies the application of the heat flux relationships part of the model. All heat entering the water is assumed to be immediately distributed both vertically and transversely. All heat leaving the water is a function of this homogeneous water temperature. Flowing water generally mixes at a far faster rate as a result of the turbulence than due to either conduction or convection within the water.

The model can, and has been, used satisfactorily to evaluate the impact of the following factors on instream water temperature:

(1) Riparian vegetation (past, existing, and proposed);

(2) Reservoir releases (discharge rates and temperatures); and

(3) Stream withdrawals and returns.

The model has been used in large basins (e.g., the Upper Colorado River Basin) to study the impact of water temperature on endangered species (Theurer et al. 1982). It also has been used in smaller, ungaged watersheds to study the impacts of riparian vegetation on salmonid habitat (Theurer et al., in press). The model also has been used several times to evaluate the impact of reservoir releases on water temperature immediately below a dam.

Various solution techniques, ranging from hand-held calculator to computer programs, directly offer the user reasonable answers for each application. The selection of the proper solution technique depends on the complexity of the application, volume of computations involved, and availability of hardware to perform the calculations. The software for all the solution techniques is available to the user through IFASG (see Part IV).

BASIC DATA SOURCES

Meteorology

Only four basic meteorological input parameters are needed: (1) mean daily air temperature; (2) mean daily relative humidity; (3) mean daily wind speed; and (4) sunshine ratio or cloud cover during daylight hours. Each parameter must be averaged over the chosen time period for analysis. Information on all four parameters are available either directly or with minor computations from published weather data. The National Oceanic and Atmospheric Administration (NOAA) publishes Local Climatological Data (LCD) for numerous weather stations throughout the Nation. These LCD's contain monthly time period averages for the specified year and monthly normals for the entire period of record to date.

If time periods other than months are desired, daily records need to be obtained and averages computed for the selected time period. Some daily data can be obtained from the U.S. Weather Bureau, U.S. Soil Conservation Service snowtel data, local airports, military bases, and personal weather stations. However, most applications should be able to use the LCD's with, at most, limited adjustments.

When the model is being used to predict the future impacts of various proposals (gaming), only a limited set of meteorological conditions probably would be needed. The normals (approximately 50% chance of occurrence) would be of paramount interest. An extreme or two might be needed to represent a cold and/or a hot year. This information could be obtained by extracting respresentative years from historical data or synthetically developing the data using frequency analysis. The choice of a source for meteorological data is independent of the model; however, the validity of predicted water temperatures is closely tied to the validity of the input data.

Hydrology

The hydrology input data consist of discharges at all specified points throughout the stream network and water temperatures at only certain points. The transport model requires known water temperatures for all headwaters, reservoir structures, and other beginning points in the network. If validation or calibration is desired, known water temperatures also are necessary at these points.

The regression models are used to synthesize the known water temperatures at a specific network point so that water temperatures under different meteorological or hydrological conditions can be predicted. However, the regression model only predicts water temperatures at the specific network point for which the regression analysis applies. The transport model is necessary for longitudinal water temperature predictions.

Discharge data are necessary for each hydrology node in the network. A hydrology node is a point in the network where a discontinuity in hydrology occurs; e.g., the junction of a tributary with the main stem. Discharges are assumed to vary linearly (lateral flow) between nodes. Therefore, the hydrology network requires a sufficient number of nodes to represent the major tributaries and any significant changes in lateral flow.

The discharge values at each hydrology node can be obtained from historical records, the use of synthetic procedures, or both. The U.S. Geological Survey (USGS) has discharge data for many stations throughout the Nation. Water temperature data are available for some of these stations. Some data are available from published USGS Water Resources Data and Water Quality Records; additional data can be obtained through the USGS WATSTOR system. The use of historical records requires a hydrologic analysis to determine the discharges at the remaining, ungaged hydrology nodes. An experienced hydrologist is needed to identify the necessary representative hydrology nodes and to determine the actual discharges for proper hydrologic balancing.

Hydrology data frequently need to be developed entirely by synthetic means for ungaged basins. Accepted procedures exist that can be used to synthetically determine discharges throughout a basin using rainfall-runoff models. This step requires an experienced hydrologist.

Starting water temperatures at headwaters can be determined synthetically by a separate water temperature study. For example, assume that a headwater node is located on a tributary that has a significant drainage area and is a short distance upstream from a junction. This headwater drainage area can be represented as a single stream reach up to the upper end (point of zero discharge). All flows contributing to the total discharge at the downstream end (original headwater node) are assumed to be lateral flows. The transport model can be used to calculate the water temperature at this downstream point, assuming zero discharge at the upstream end. The starting water temperature is not relevant because there is no water (and no heat) in the stream at this upstream end. Therefore, an initial water temperature of zero is used at the point of zero discharge. This procedure has been used satisfactorily by the SCS for the Tucannon River in the Columbia River Basin (Theurer et al., in press).

Stream Geometry

The stream geometry data consist of: (1) the stream geometry network; (2) the elevation and upstream distances of each node; and (3) the average stream width, hydraulic retardence, and shading parameters associated with the reach below each node.

The stream geometry network has to have a sufficient number of nodes to represent the stream system. It will include many of the same nodes as the hydrology network; e.g., tributary junctions. However, the network also may contain additional nodes because of certain geometric differences that do not affect discharge; e.g., the riparian vegetation may change significantly. All distances should be measured from a common downstream point; generally, the farthest downstream end point of the network. All distance and the basic network configuration data can be obtained directly from USGS quad sheets, if field survey data are not readily available.

Average stream width information should be obtained from field measurements, but can be supplemented with aerial photos. Hydraulic retardence data (n-value) also are obtained from field observations (by an experienced hydrologist); they can be refined later with hydraulic calculations. Retardence information is necessary only if estimates of diurnal fluctuations are desired.

The shading parameters consist of stream azimuth, topographic sunrise/sunset angles, and riparian vegetation parameters. Information on both stream azimuth and topographic angles can be obtained from USGS quad sheets, as well as field observations. The riparian vegetation parameters must be obtained from field observations and measurements. Aerial photos are useful only for measuring the longitudinal extent of a parameter.

If the temperature study is being conducted concurrent with, or subsequent to, a network hydrologic/hydraulic analysis, the only additional stream geometry data needed are the shading parameters.

Solar

The solar model incorporates almost all the meteorological, hydrological, and stream geometry data in order to determine the solar radiation penetrating the water surface. The only additional inputs necessary are the dust and ground reflectivity coefficients. These coefficients can be obtained from the tables included in Part III of this paper or may be calibrated from measured solar radiation data found in Cinquemani et al. (1978).

USE OF SOLUTION TECHNIQUES

At this time, there are four different solution techniques to help solve the instream water temperature model: (1) the HP-34C program; (2) the HP-41C programs; (3) BASIC source code for microcomputers; and (4) FORTRAN 77 source code for larger computers. Each technique is designed for certain types of applications; however, each technique can be updated to increase its scope. Certain applications may suggest the use of two solution techniques, one for one part and a second for the remainder. For example, the HP-41C solar model can be used to calibrate the dust and ground reflectivity coefficients for solar radiation and the FORTRAN 77 computer program used for all else.

HP-34C Program

The HP-34C program (hand-held calculator) is a very simplified solution of the heat transport model only and should be used only on the simplest of applications where ground level solar radiation and shading are already known. An example would be a screening study immediately below a reservoir, based on normal meteorological conditions.

HP-41C Program

The HP-41C programs (desk-top calculator) have solutions for all the instream water temperature models and are limited only by the tediousness of manually recording results for each node and the slowness of the actual computations. Therefore, applications in networks that contain a large number of nodes and/or require many time period analyses are not appropriate to solve on the HP-41C. Certain portions of this solution technique can be used to supplement the computer program, such as the solar radiation program. The HP-41C programs are designed for intermediate-sized networks, for limited time period analyses, and to supplement other solution techniques.

BASIC Program

The BASIC program, like the HP-34C, is a highly simplified solution of the heat transport model. It can be applied only on single reaches, using a single set of meteorological conditions. However, it does provide a useful gaming environment for testing extreme meteorological conditions. For example, the BASIC program would be ideal for determining the flow that would be required from a reservoir to prevent ice formation at a specified distance downstream.

FORTRAN 77 Program

The FORTRAN 77 program is designed for the largest networks possible and an unlimited number of time period analyses. The program can be used for stand-alone water temperature studies or linked to other computer programs (e.g., a hydrology program) through the computer program file system.

The FORTRAN 77 program has the greatest growth potential because of its portability and linkage capabilities. A reservoir temperature model can be linked to this program to supply the expected discharge-temperature-time period release data. Reservoir models require at least the same meteorological and solar data as the instream model. Hydrology models can be linked to this program to provide the expected discharge data. Fish temperature criteria can be linked to the output temperature data for direct interpretation by the biologist.

EXAMPLE APPLICATIONS

Upper Colorado River Basin

The Upper Colorado River Basin (UCRB) was the nucleus about which the temperature model was first developed. A site-specific computer program was written and used as a part of a U.S. Fish and Wildlife Service study (Prewitt et al. 1981; Theurer and Voos 1982; Theurer et al. 1982). A generalized computer program, including revisions and enhancements, was developed subsequently. This example is based on the enhanced model and the generalized computer program. The resulting water temperature predictions were not significantly different, but the enhanced model and generalized solution techniques are easier to use and applicable to a broad variety of basins.

The instream water temperature model assumes that three basic subsets of input data are available: (1) stream system geometry; (2) meteorology; and (3) hydrology. The stream system geometry input was site specific. The meteorology data consisted of historical records from water years 1959-60 through 1981-82. The hydrology data included historical flows for the same times so that regression models could be developed and used to predict the initial water temperatures of headwaters to validate the overall model. The hydrology data also include the ability to "game" with the flow information to determine the normal temperature regimes.

Stream system geometry. The temperature model was applied to the Green and Colorado River networks (Fig. I.1). The Green River was modeled from below Flaming Gorge Dam, using the Greendale gage for estimates of initial flows and temperatures. Most of the tributaries emptying into the Green River were modeled from gages close to the tributary junctions, including all tributaries with flows recorded near the confluence with the Green River (the Duchesne, Price, and San Rafael Rivers). The White River was modeled from the gage near Watson, Utah. The Yampa River was modeled from above the confluence with the Little Snake River. Recorded flows and temperatures from the Little Snake gage near Lily, Colorado, and the Yampa River gage near Maybell, Colorado, were used. The Colorado River was modeled from the gage near Cameo, Colorado. The Gunnison River was modeled from the gage near Grand Junction, Colorado. The Dolores River was modeled from a gage close to its junction with the Colorado River.

The hydrology subnet allowed for one diversion upstream of Green River, Utah, on the Green River (and subsequent return flow below Green River) and one diversion upstream of Grand Junction, Colorado, on the Colorado River, with the return flow downstream of Grand Junction.

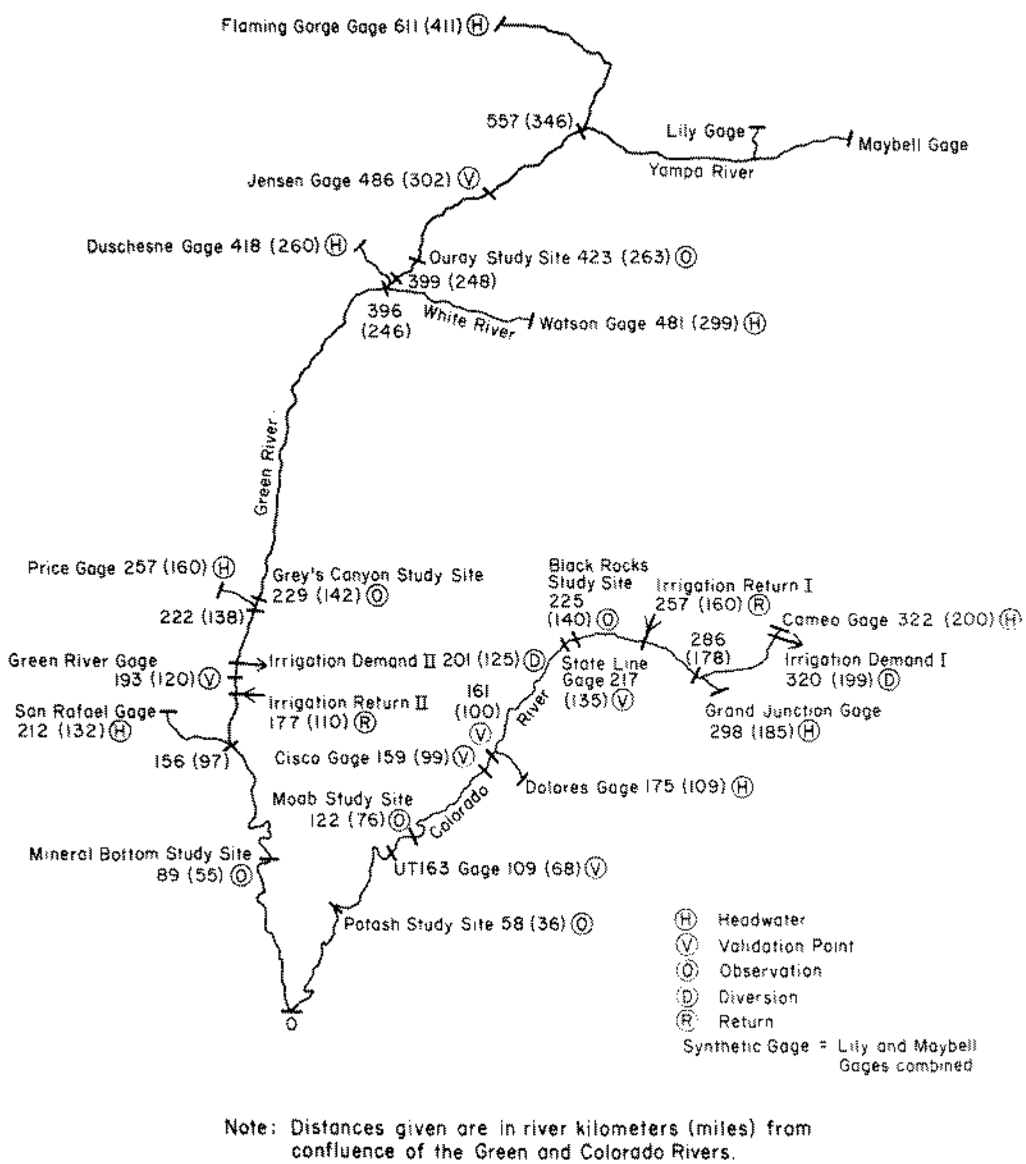


Figure I.1. Upper Colorado River Basin network.

USGS Plan and Profile maps, USGS Fifteen Minute Series quadrangle maps, and field observations were used to determine elevations, stream slopes, site locations (river miles and latitude/longitude), and the extent of solar shading due to canyon walls.

Hydrology. The data file for fifteen gages was developed from the U.S. Geological Survey Water Resources Data for Colorado and Water Resources Data for Utah (Guy and Theurer 1984). Discharges and water temperatures were summarized from daily USGS WATSTOR data and supplemented with published USGS Water Supply and Water Quality Papers. Two diversions and two associated returns were assumed, one on the Green River and one on the Colorado River. Return flows were assumed to be 70% of the diversion. The diversion on the Green River was assumed to be zero, except when calculated lateral flows would have been zero. In this case, the diversion was assumed to account for the slack or difference. The diversion on the Colorado River below Cameo was based on analysis of historical records and set equal to 1,610 cfs from May through October and zero the rest of the year. Lateral flows were assumed to account for the difference in discharges between gages.

Meteorology. Climatological data were developed from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration records for Grand Junction, Colorado. Local Climatological Data, Annual Summary, 1950-1982, were used for the average daily information on air temperature, wind speed, percent possible sunshine, and relative humidity. Normals for the period of record also were taken from the Annual Summary.

Minimum/Maximum water temperatures. The heat transport model calculates the average daily water temperature and diurnal fluctuations from a minimum just before sunrise to a maximum just before sunset. The maximum daytime water temperature model was calculated for the normal monthly discharges and meteorological conditions. Table I.1 presents the diurnal water temperature fluctuations for each month. These data can be interpreted as indicative of the anticipated diurnal fluctuation about the average daily for a specified month, applicable for any year. For example, the fluctuation in water temperature about the average daily for normal June conditions ranged from 1.81 C at the Ouray study site to 2.12 C at the Mineral Bottom study site. The month of June can be expected to show a similar fluctuation in any year.

If there was a serious depletion in flow over the current normal discharges in any month, the anticipated fluctuation would be greater because the water temperature would more closely approach the equilibrium water temperature. The average daily water temperature would reflect this trend also, but the daily water temperature cycle would be accentuated.

Tucannon River

This example illustrates the important relationship between riparian vegetation, water temperature, and salmonid habitat. The water temperature responses of the Tucannon River to different riparian vegetation conditions are explained. Then, the salmonid populations are related to aquatic habitat, as affected by water temperature. An economic evaluation is included to demonstrate both the importance and the practicality of restoring a favorable aquatic habitat for salmonids.

Table I.1. Diurnal water temperature fluctuations (±C).[a]

	Study sites					
	Ouray	Grey's Canyon	Mineral Bottom	Black Rocks	Moab	Potash
January	0.53	0.74	0.56	0.86	0.69	0.61
February	0.71	0.97	0.70	1.20	0.96	0.84
March	0.89	1.17	0.81	1.49	1.21	1.03
April	0.77	1.12	0.77	1.44	1.07	0.89
May	0.61	0.90	0.59	1.06	0.82	0.66
June	0.64	0.88	0.58	1.02	0.78	0.66
July	0.96	1.28	0.87	1.37	1.14	0.94
August	1.21	1.65	1.16	1.83	1.55	1.34
September	1.23	1.65	1.16	1.72	1.43	1.22
October	0.95	1.28	0.92	1.36	1.09	0.95
November	0.65	0.88	0.64	0.94	0.76	0.67
December	0.44	0.63	0.48	0.71	0.58	0.51

[a]Based on "normal" meteorology and average (1959-1960 through 1981-1982) hydrology without any calibration.

Watershed description. The Tucannon River watershed is located in Columbia and Garfield Counties in southeastern Washington (Fig. I.2). The river drains about 500 mi² of the 260,000 mi² Columbia River basin. It heads at an elevation of 6,500 ft in the Blue Mountains of the Umatilla National Forest and flows into the Snake River near Starbuck, Washington, at an elevation of 500 ft. The upper one-third of the watershed is on public land. The river has enough riparian vegetation and clean substrate to serve as satisfactory spawning and rearing habitat. The lower two-thirds of the watershed, however, is on private land, used mostly for agriculture. The river has lost most of its vegetation in this area and is not satisfactory habitat for either rearing or spawning. It receives an influx of fine sediments, predominantly from upland sources, and has unstable banks (Esmaili and Associates 1982). These problems are largely the result of human activities.

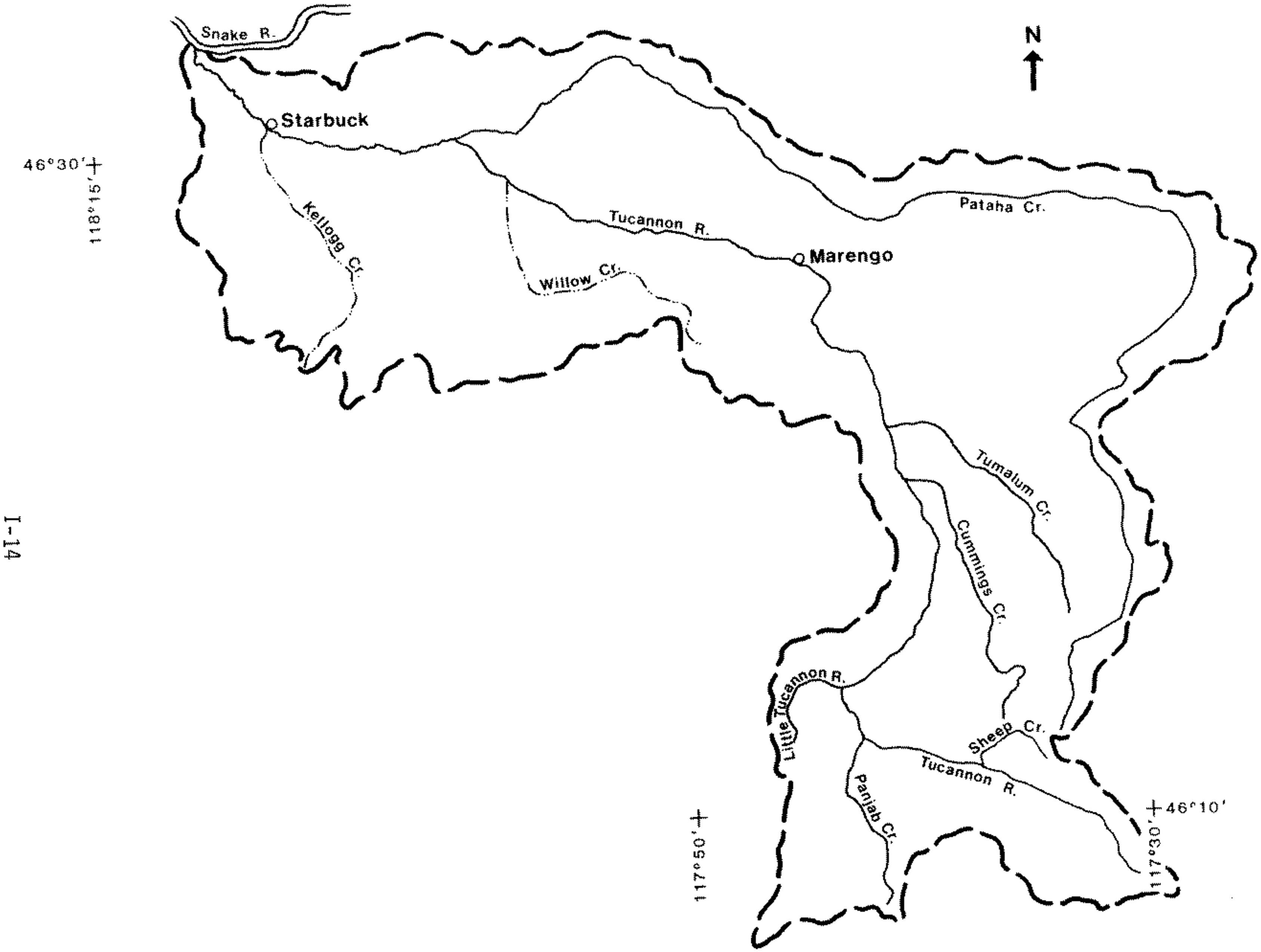


Figure I.2. Tucannon River watershed.

Stream conditions. Four riparian vegetation and channel morphology conditions were analyzed. The first condition analyzed was the existing condition; i.e., the riparian and channel conditions as of 1980. The second condition analyzed was the climax condition; i.e., what the riparian vegetation and channel morphology would be today if floods and subsequent stream channelization in the mid-60's had not destroyed the riparian vegetation below the National Forest boundary. The climax riparian vegetation was estimated by studying the existing riparian vegetation in relict riparian zones along the river. The climax channel morphology was taken from a report by Esmaili and Associates (1982). The loss of riparian vegetation resulted in bank instability in the lower end of the river, with noticeable widening and considerable straightening.

The last two conditions analyzed were revegetation alternatives. Alternative 1 assumed restoration of the riparian vegetation (stream shade) down to Pataha Creek. Alternative 2 assumed restoration of riparian vegetation as far as the Snake River. Neither alternative assumed any stream realignment or adjustments of the cross section. Both alternatives were based on the planting of young shade trees that would reach maximum effectiveness (maximum stream shade) in 20 years.

Only the months of May through September were studied because they cover the critical rearing periods of steelhead trout and chinook salmon. Interpretations of the impact of water temperature on spawning and rearing were based mostly on normal meteorological and hydrologic conditions for these months. The years 1980 and 1981 were studied because some measured water temperature data were available for validation, some fish population studies coincided with these years, and the results of predicted water temperatures for historical data gave a feel for variability about the "normals".

Stream geometry. The stream geometry data were obtained through a combination of field data, USGS published maps, and a channel morphology study by Esmaili and Associates (1982). Tables I.2 and I.3 contain the physical stream geometry data for the existing and climax conditions, respectively. The tributary shade values noted in these two tables were estimated from field observations and were not based on any shade model calculations. The mainstem Tucannon River and Sheep Creek shade values were calculated using the shade parameter data presented in Table I.4. These parameters were obtained from actual field measurements. Alternatives 1 and 2 used the pertinent data from these four tables, as applicable.

Table I.2. Tucannon River stream geometry data for existing conditions.

Stream name	Node type	Distance (km)	Drainage area (ha)	Latitude (radians)	Elevation (m)	Manning's "n"-value	Average stream width (m)	Shade (dec.)	Remarks
Tucannon River	H	103.9	0.0	0.80576	1525	.045	6.0	--	mainstem source
Tucannon River	B	91.1	6321	0.80576	1037	--	--	--	above Sheep Creek confluence
Sheep Creek	H	96.1	0.0	0.80576	1610	.050	1.5	--	source Sheep Creek
Sheep Creek	T	91.1	791	0.80576	1037	--	--	--	at Tucannon River confluence
Tucannon River	J	91.1	7112	0.80576	1037	.050	10.0	--	below Sheep Creek junction
Tucannon River	B	83.9	10,816	0.80634	915	--	--	--	above Panjab Creek confluence
Panjab Creek	H	95.1	0.0	0.80605	1525	.050	3.0	.1300	source Panjab Creek
Panjab Creek	T	83.9	5698	0.80634	915	--	--	--	at Tucannon River confluence
Tucannon River	J	83.9	16,514	0.80634	915	.045	13.0	--	below Panjab Creek junction
Tucannon River	B	80.5	17,548	0.80663	854	--	--	--	above Little Tucannon River confluence
Ltl. Tuc. River	H	88.5	0.0	0.80634	1464	.058	1.0	.9000	source Little Tucannon River
Ltl. Tuc. River	T	80.5	1899	0.80663	854	--	--	--	at Tucannon River confluence
Tucannon River	J	80.5	19,447	0.80663	854	.045	13.0	--	below Little Tucannon River junction
Tucannon River	C	77.0	20,555	0.80721	808	.045	15.0	--	at Camp Wooten Bridge
Tucannon River	C	74.2	21,262	0.80780	784	.045	12.0	--	at four lakes diversion
Tucannon River	C	70.2	22,402	0.80780	701	.050	15.0	--	National Forest boundary
Tucannon River	C	68.2	22,972	0.80809	695	.050	15.0	--	at Deer Lake diversion

Table I.2. (continued)

Stream name	Node type	Distance (km)	Drainage area (ha)	Latitude (radians)	Elevation (m)	Manning's "n"-value	Average stream width (m)	Shade (dec.)	Remarks
Tucannon River	C	65.6	23,721	0.80809	689	.050	15.0	--	at Deer Lake return
Tucannon River	C	64.0	24,185	0.80838	678	.050	15.0	--	at Rainbow Lake diversion
Tucannon River	C	62.4	25,473	0.80838	658	.060	18.0	--	State fish hatchery
Tucannon River	B	59.4	26,507	0.80896	610	--	--	--	above Cummins Creek confluence
Cummins Creek	H	76.8	0.0	0.80838	1524	.045	1.0	.9000	source Cummins Creek
Cummins Creek	T	59.4	5044	0.80896	610	--	--	--	at Tucannon River confluence
Tucannon River	J	59.4	31,550	0.80896	610	.060	20.0	--	below Cummins Creek junction
Tucannon River	B	55.4	32,500	0.80925	579	--	--	--	above Tumalume Creek confluence
Tumalume Creek	H	72.8	0.0	0.80896	1433	.050	1.0	.8000	source Tumalume Creek
Tumalume Creek	T	55.4	4157	0.80925	579	--	--	--	at Tucannon River confluence
Tucannon River	J	55.4	36,658	0.80925	579	.060	18.0	--	below Tumalume Creek junction
Tucannon River	C	51.4	37,945	0.80954	549	.060	19.0	--	Bridge No. 13
Tucannon River	C	47.0	39,370	0.81012	501	.050	16.0	--	Bridge No. 11
Tucannon River	C	42.8	40,720	0.81041	476	.050	16.0	--	Bridge No. 9
Tucannon River	C	41.7	41,079	0.81071	448	.050	17.0	--	below Marengo Bridge
Tucannon River	C	35.6	44,899	0.81100	388	.050	16.0	--	King's Grade Bridge
Tucannon River	B	23.5	49,489	0.81158	275	--	--	--	above Willow Creek confluence

Table I.2. (concluded)

Stream name	Node type	Distance (km)	Drainage area (ha)	Latitude (radians)	Elevation (m)	Manning's "n"-value	Average stream width (m)	Shade (dec.)	Remarks
Willow Creek	H	42.5	0.0	0.81100	731				source Willow Creek
						.050	0.5	.0200	
Willow Creek	T	23.5	7756	0.81158	275				at Tucannon River confluence
						--	--	--	
Tucannon River	J	23.5	57,245	0.81158	275				below Willow Creek junction
						.050	16.0	--	
Tucannon River	C	21.5	58,258	0.81158	273				above Krouse's diversion
						.050	15.0	--	
Tucannon River	B	19.5	59,334	0.81158	264				above Pataha Creek confluence
						--	--	--	
Pataha Creek	H	101.5	0.0	0.81100	1280				source Pataha Creek
						.035	3.0	.2000	
Pataha Creek	T	19.5	48,518	0.81158	264				at Tucannon River confluence
						--	--	--	
Tucannon River	J	19.5	107,852	0.81158	264				below Pataha Creek junction
						.050	20.0	--	
Tucannon River	C	15.1	110,574	0.81158	234				above Fletcher's diversion
						.050	20.0	--	
Tucannon River	C	13.4	111,630	0.81158	195				USGS gage near Starbuck
						.050	20.0	--	
Tucannon River	C	9.0	114,341	0.81158	185				above hog farmers' diversion
						.050	20.0	--	
Tucannon River	B	7.6	122,867	0.81216	180				above Kellogg Creek confluence
						--	--	--	
Kellogg Creek	H	23.7	0.0	0.81158	610				source Kellogg Creek
						.035	1.0	.0200	
Kellogg Creek	T	7.6	2659	0.81216	180				at Tucannon River confluence
						--	--	--	
Tucannon River	J	7.6	125,527	0.81216	180				below Kellogg Creek junction
						.050	20.0	--	
Tucannon River	E	0.0	131,678	0.81216	150				at Snake River confluence
						--	--	--	

Table I.3. Tucannon River stream geometry data for climax conditions.

Stream name	Node type	Distance (km)	Drainage area (ha)	Latitude (radians)	Elevation (m)	Manning's "n"-value	Average stream width (m)	Shade (dec.)	Remarks
Tucannon River	H	107.4	0.0	0.80576	1525	.045	6.0	--	mainstem source
Tucannon River	B	94.6	6321	0.80576	1037	--	--	--	above Sheep Creek confluence
Sheep Creek	H	99.6	0.0	0.80576	1610	.050	1.5	--	source Sheep Creek
Sheep Creek	T	94.6	791	0.80576	1037	--	--	--	at Tucannon River confluence
Tucannon River	J	94.6	7112	0.80576	1037	.050	10.0	--	below Sheep Creek junction
Tucannon River	B	87.4	10,816	0.80634	915	--	--	--	above Panjab Creek confluence
Panjab Creek	H	98.6	0.0	0.80605	1525	.050	3.0	.1300	source Panjab Creek
Panjab Creek	T	87.4	5698	0.80634	915	--	--	--	at Tucannon River confluence
Tucannon River	J	87.4	16,514	0.80634	915	.045	12.0	--	below Panjab Creek junction
Tucannon River	B	84.0	17,548	0.80663	854	--	--	--	above Little Tucannon River confluence
Ltl. Tuc. River	H	92.0	0.0	0.80634	1464	.058	1.0	.9000	source Little Tucannon River
Ltl. Tuc. River	T	84.0	1899	0.80663	854	--	--	--	at Tucannon River confluence
Tucannon River	J	84.0	19,447	0.80663	854	.045	12.0	--	below Little Tucannon River junction
Tucannon River	C	80.5	20,555	0.80721	808	.045	12.0	--	at Camp Wooten Bridge
Tucannon River	C	77.7	21,262	0.80780	784	.045	12.0	--	at four lakes diversion
Tucannon River	C	73.7	22,402	0.80780	701	.050	12.0	--	National Forest boundary
Tucannon River	C	71.7	22,972	0.80809	695	.050	12.0	--	at Deer Lake diversion

Table I.3. (continued)

Stream name	Node type	Distance (km)	Drainage area (ha)	Latitude (radians)	Elevation (m)	Manning's "n"-value	Average stream width (m)	Shade (dec.)	Remarks
Tucannon River	C	69.1	23,721	0.80809	689	.050	12.0	--	at Deer Lake return
Tucannon River	C	67.5	24,185	0.80838	678	.050	12.0	--	at Rainbow Lake diversion
Tucannon River	C	65.9	25,473	0.80838	658	.060	13.0	--	State fish hatchery
Tucannon River	B	62.9	26,507	0.80896	610	--	--	--	above Cummins Creek confluence
Cummins Creek	H	80.3	0.0	0.80838	1524	.045	1.0	.9000	source Cummins Creek
Cummins Creek	T	62.9	5044	0.80896	610	--	--	--	at Tucannon River confluence
Tucannon River	J	62.9	31,550	0.80896	610	.060	13.0	--	below Cummins Creek junction
Tucannon River	B	58.9	32,500	0.80925	579	--	--	--	above Tumalume Creek confluence
Tumalume Creek	H	76.3	0.0	0.80896	1433	.050	1.0	.8000	source Tumalume Creek
Tumalume Creek	T	58.9	4157	0.80925	579	--	--	--	at Tucannon River confluence
Tucannon River	J	58.9	36,658	0.80925	579	.060	14.0	--	below Tumalume Creek junction
Tucannon River	C	54.6	37,945	0.80954	549	.060	14.0	--	Bridge No. 13
Tucannon River	C	50.3	39,370	0.81012	501	.050	14.0	--	Bridge No. 11
Tucannon River	C	46.6	40,720	0.81041	476	.050	15.0	--	Bridge No. 9
Tucannon River	C	44.6	41,079	0.81071	448	.050	15.0	--	below Marengo Bridge
Tucannon River	C	38.5	44,899	0.81100	388	.050	15.0	--	King's Grade Bridge
Tucannon River	B	24.9	49,489	0.81158	275	--	--	--	above Willow Creek confluence

Table I.3. (concluded)

Stream name	Node type	Distance (km)	Drainage area (ha)	Latitude (radians)	Elevation (m)	Manning's "n"-value	Average stream width (m)	Shade (dec.)	Remarks
Willow Creek	H	43.9	0.0	0.81100	731	.050	0.5	.0200	source Willow Creek
Willow Creek	T	24.9	7756	0.81158	275	--	--	--	at Tucannon River confluence
Tucannon River	J	24.9	57,245	0.81158	275	.050	15.0	--	below Willow Creek junction
Tucannon River	C	22.8	58,258	0.81158	273	.050	15.0	--	above Krouse's diversion
Tucannon River	B	20.7	59,334	0.81158	264	--	--	--	above Pataha Creek confluence
Pataha Creek	H	102.8	0.0	0.81100	1280	.035	3.0	.2000	source Pataha Creek
Pataha Creek	T	20.7	48,518	0.81158	264	--	--	--	at Tucannon River confluence
Tucannon River	J	20.7	107,852	0.81158	264	.050	16.0	--	below Pataha Creek junction
Tucannon River	C	15.9	110,574	0.81158	234	.050	16.0	--	above Fletcher's diversion
Tucannon River	C	14.0	111,630	0.81158	195	.050	16.0	--	USGS gage near Starbuck
Tucannon River	C	9.2	114,341	0.81158	185	.050	16.0	--	above hog farmers' diversion
Tucannon River	B	7.6	122,867	0.81216	180	--	--	--	above Kellogg Creek confluence
Kellogg Creek	H	23.7	0.0	0.81158	610	.035	1.0	.0200	source Kellogg Creek
Kellogg Creek	T	7.6	2659	0.81216	180	--	--	--	at Tucannon River confluence
Tucannon River	J	7.6	125,527	0.81216	180	.050	17.0	--	below Kellogg Creek junction
Tucannon River	E	0.0	131,678	0.81216	150	--	--	--	at Snake River confluence

Table I.4. Shade parameters for mainstem Tucannon River and Sheep Creek.

Existing conditions							Climax conditions						
Distance (km)	Stream azimuth (rad.)	Topo. altitude (rad.)	Crown measure-ment (m)	Height (m)	Offset (m)	Density (dec.)	Distance (km)	Stream azimuth (rad.)	Topo. altitude (rad.)	Crown measure-ment (m)	Height (m)	Offset (m)	Density (dec.)
Sheep Creek													
96.1	0.7854	.4363	5.0	25.0	0.5	.98	99.6	0.7854	.4363	5.0	25.0	0.5	.98
		.4363	5.0	25.0	0.5	.98			.4363	5.0	25.0	0.5	.98
Mainstem Tucannon River													
103.9	-1.0996	.4363	5.0	25.0	0.5	.98	107.4	-1.0996	.4363	5.0	25.0	0.5	.98
		.4363	5.0	25.0	0.5	.98			.4363	5.0	25.0	0.5	.98
91.1	-1.2217	.4363	5.0	25.0	0.5	.98	94.6	-1.2217	.4363	5.0	25.0	0.5	.98
		.4363	5.0	25.0	0.5	.98			.4363	5.0	25.0	0.5	.98
83.9	-0.5061	.4363	3.0	5.0	0.5	.50	87.4	-0.5061	.4363	5.0	20.0	0.5	.90
		.5236	5.0	8.0	0.5	.90			.5236	5.0	20.0	0.5	.90
80.5	0.9425	.6109	5.0	30.0	3.0	.90	84.0	0.9425	.6109	5.0	30.0	0.5	.90
		.3491	5.0	30.0	3.0	.80			.3491	5.0	30.0	0.5	.90
77.0	0.5061	.4363	5.0	20.0	2.0	.80	80.5	0.5061	.4363	5.0	20.0	0.5	.90
		.4363	5.0	20.0	2.0	.75			.4363	5.0	20.0	0.5	.90
74.2	0.1047	.4363	5.0	25.0	0.5	.90	77.7	0.1047	.4363	5.0	25.0	0.5	.90
		.4363	5.0	25.0	0.5	.80			.4363	5.0	25.0	0.5	.90
70.2	-0.1920	.3491	5.0	25.0	1.0	.60	73.7	-0.1920	.3491	5.0	25.0	0.5	.90
		.4363	5.0	20.0	1.0	.60			.4363	5.0	20.0	0.5	.90
68.2	-0.1920	.3491	5.0	25.0	1.0	.60	71.7	-0.1920	.3491	5.0	25.0	0.5	.90
		.4363	5.0	20.0	1.0	.60			.4363	5.0	20.0	0.5	.90
65.6	-0.1920	.3491	5.0	25.0	1.0	.60	69.1	-0.1920	.3491	5.0	25.0	0.5	.90
		.4363	5.0	20.0	1.0	.60			.4363	5.0	20.0	0.5	.90
64.0	-0.1920	.3491	5.0	25.0	1.0	.60	67.5	-0.1920	.3491	5.0	25.0	0.5	.90
		.4363	5.0	20.0	1.0	.60			.4363	5.0	20.0	0.5	.90
62.4	-0.5411	.3491	5.0	12.0	2.0	.60	65.9	-0.5411	.3491	5.0	20.0	0.5	.90
		.3840	5.0	12.0	1.0	.60			.3840	5.0	20.0	0.5	.90
59.4	-0.2793	.2618	5.0	9.0	2.0	.40	62.9	-0.2793	.2618	5.0	20.0	0.5	.90
		.2618	5.0	12.0	1.0	.70			.2618	5.0	20.0	0.5	.90
55.4	-0.2269	.3142	4.0	6.0	2.0	.20	58.9	-0.2269	.3142	7.0	20.0	0.5	.80
		.2443	6.0	8.0	2.0	.20			.2443	7.0	20.0	0.5	.80

Table I.4. (concluded)

Existing conditions							Climax conditions						
Distance (km)	Stream azimuth (rad.)	Topo. altitude (rad.)	Crown measurement (m)	Height (m)	Offset (m)	Density (dec.)	Distance (km)	Stream azimuth (rad.)	Topo. altitude (rad.)	Crown measurement (m)	Height (m)	Offset (m)	Density (dec.)
51.4	-0.8901	.1745	7.0	7.0	2.0	.20	54.6	-0.8901	.1745	10.0	25.0	1.0	.80
		.2793	7.0	7.0	2.0	.40			.2793	10.0	25.0	1.0	.80
47.0	0.3142	.2094	8.0	7.0	2.0	.60	50.3	0.3142	.2094	10.0	25.0	1.0	.80
		.4363	8.0	7.0	2.0	.60			.4363	10.0	25.0	1.0	.80
42.8	-0.9076	.1571	7.0	10.0	2.0	.50	46.6	-0.9076	.1571	10.0	25.0	1.0	.80
		.3491	7.0	7.0	2.0	.30			.3491	10.0	25.0	1.0	.80
41.7	-1.2217	.0873	7.0	7.0	5.0	.60	44.6	-1.2217	.0873	10.0	25.0	1.0	.80
		.1745	7.0	7.0	5.0	.60			.1745	10.0	25.0	1.0	.80
35.6	-1.1868	.1396	7.0	7.0	5.0	.50	38.5	-1.1868	.1396	10.0	25.0	1.0	.80
		.1745	7.0	7.0	5.0	.50			.1745	10.0	25.0	1.0	.80
23.5	-0.8203	.2967	7.0	7.0	1.0	.50	24.9	-0.8203	.2967	10.0	25.0	1.0	.80
		.1745	7.0	7.0	1.0	.50			.1745	10.0	25.0	1.0	.80
21.5	-0.8203	.2967	7.0	7.0	1.0	.50	22.8	-0.8203	.2967	10.0	25.0	1.0	.80
		.1745	7.0	7.0	1.0	.50			.1745	10.0	25.0	1.0	.80
19.5	-1.3963	.0873	7.0	6.0	5.0	.30	20.7	-1.3963	.0873	10.0	25.0	2.0	.60
		.1396	7.0	7.0	5.0	.30			.1396	10.0	25.0	2.0	.60
15.1	-1.3963	.0873	7.0	6.0	5.0	.30	15.9	-1.3963	.0873	10.0	25.0	2.0	.60
		.1396	7.0	7.0	5.0	.30			.1396	10.0	25.0	2.0	.60
13.4	-1.3963	.0873	7.0	6.0	5.0	.30	14.0	-1.3963	.0873	10.0	25.0	2.0	.60
		.1396	7.0	7.0	5.0	.30			.1396	10.0	25.0	2.0	.60
9.0	-1.3963	.0873	7.0	6.0	5.0	.30	9.2	-1.3963	.0873	10.0	25.0	2.0	.60
		.1396	7.0	7.0	5.0	.30			.1396	10.0	25.0	2.0	.60
7.6	-0.7679	.0349	4.0	5.0	5.0	.20	7.6	-0.7679	.0349	10.0	25.0	2.0	.50
		.0873	4.0	5.0	5.0	.20			.0873	10.0	25.0	2.0	.50

Note: East side values are listed on the first line, west side values on the second line.

The stream network consists of the mainstem and significant tributaries (herringbone-complexity, second-order). The sequence was as shown in Tables I.2 and I.3. The node types are defined as:

B - branch to tributary

C - change in stream geometry

D - diversion of streamflow

E - end of network

H - headwater

J - junction of a branch and tributary

K - calibration

M - meteorology change

O - output

P - point source

Q - discharge

R - return flow

S - reservoir structure

T - tributary terminal

V - validation

Some of the above node types were not used in the Tucannon stream geometry tables (Tables I.2 and I.3).

The shade parameters for Sheep Creek (Table I.4) were the average conditions for the entire tributary. Shade parameters for the mainstem Tucannon River were the average conditions for the stream reach downstream to the next reach. The topographic altitude was the average angle of the local topography above the horizon in each reach. It was used to calculate local sunrise and sunset times, which were used to determine topographic shading. The shade provided by riparian vegetation was calculated from the vegetation parameters crown measurement, height of vegetation, offset distance from the water's edge, and density. The shade parameters were used together with the latitude and average stream width obtained from the physical stream geometry data to determine shade.

The differences between Tables I.2 and I.3 (existing and climax conditions) are in the distance locations of the nodes and the stream widths. These reflect the straightening and widening of the stream subsequent to the mid-1960 storms. The differences between existing and climax conditions

(Table I.4) reflect the loss of riparian vegetation, also resulting from the mid-1960 storms.

Hydrology. The U.S. Geological Survey (USGS) has maintained a streamflow gage near Starbuck for several years. Esmaili and Associates (1982), under contract with SCS, monitored the Tucannon streamflows at six gaging stations from October 1979 through September 1980. They established five gages; the sixth gage was the USGS gage near Starbuck.

Two of the gages were established in Pataha Creek, which is a major tributary of the Tucannon River. The remaining four were along the mainstem. A single, nondimensional power curve was fitted to the data to describe streamflow distribution as a function of drainage area. The equation was:

$$Q^* = \alpha \, A^{*\beta}$$

where Q^* ≡ ratio of streamflow to reference streamflow

A^* ≡ ratio of drainage area at point of streamflow to reference drainage area

α, β ≡ "best-fit" coefficients

The USGS gage near Starbuck was used as the reference location because it was used to determine the network discharges for all other years. The resulting coefficients were:

$$\alpha = 1.0299$$
$$\beta = 0.2316$$

The correlation coefficient (r) was 0.9980 and the probable error (ε) was 0.075 cms when all 20 data points were used; i.e., the four mainstem locations for each of the 5 months from May through September, 1980. Table I.5 is a summary of the observed streamflows versus the streamflows predicted from the power curve.

The correlation coefficient (r) was determined using the basic definitions of explained variation to the total. The probable error (ε) is a value that indicates that 50% of the predicted values are expected to be within the observed values and is defined as:

$$\varepsilon = 0.6745 \, S_d \sqrt{(1-r^2)(N-1)/(N-2)}$$

where S_d ≡ standard deviation of observed flow data (1.712 cms)

N ≡ number of observed flows in data set (20)

r ≡ correlation coefficient (0.9980)

Table I.5. Summary of observed versus predicted streamflows in the mainstem Tucannon River.

		State fish hatchery	Krouse Ranch	USGS gage near Starbuck	Powers Road
Dist. (km)		62.4	21.5	13.4	9.0
Drainage area (ha)		25,478	58,258	111,630	129,093
		1980 mean monthly streamflow (cms)			
May	obs.	5.989	7.634	8.317	8.555
	pred.	6.083	7.368	8.566	8.859
June	obs.	4.066	4.938	5.253	5.479
	pred.	3.842	4.654	5.410	5.595
July	obs.	1.858	2.166	2.430	2.662
	pred.	1.777	2.153	2.503	2.588
August	obs.	1.314	1.773	1.880	2.050
	pred.	1.375	1.666	1.936	2.003
September	obs.	1.269	1.855	1.982	2.169
	pred.	1.450	1.756	2.041	2.111

Table I.6 contains the recorded USGS mean monthly streamflows near Starbuck from May through September for 1980, 1981, and normal years.

Table 1-6. Recorded streamflows at USGS gage near Starbuck.

	Mean monthly streamflow (cms)				
Year	May	June	July	August	September
1980	8.317	5.253	2.430	1.880	1.982
1981	5.409	5.097	2.192	1.475	1.665
normal	8.019	5.426	2.212	1.733	2.073

The power curve was used to distribute the mean monthly streamflows along the mainstem below the junction of the Little Tucannon River. At a tributary confluence, the discharge was calculated along the mainstem by the power curve both above and below the confluence. The difference between these two values was attributed to the respective tributaries. The major source of water above the junction of the Tucannon and Little Tucannon Rivers was snowmelt. Therefore, streamflow was distributed according to drainage area; i.e., a constant discharge per unit area based on the flow and drainage area below the junction.

Diversions for local irrigation and subsequent return flows were estimated based on interviews with local irrigators and operators and records maintained by the local SCS district office. Table I.7 gives the location and amounts of diversions and returns for May through September. No year-to-year difference is assumed. Return flows were assumed to be at equilibrium water temperatures.

Because synthetic discharges had to be generated throughout the stream system network, starting water temperatures also had to be generated synthetically. This was done by beginning all tributary headwaters at their respective sources; i.e., points of zero discharges. Therefore, all incoming water was assumed to be uniformly distributed as lateral flows between designated points of "known" discharge in the stream. Lateral flow was a combination of snowmelt and ground water and both arrived at the stream at very nearly the local mean annual air temperature. The local mean annual air temperature ranged from about 4 C near the source of the snowmelt to nearly 12.5 C near the confluence of the Tucannon with the Snake River.

Meteorology. The meteorological data (air temperature, relative humidity, wind speed, and possible sunshine) were transposed from the Walla Walla, Washington, climatological data station (NOAA 1981) to the Forest Service fire guard station at the National Forest boundary in the basin. The data were judged to be in good agreement with unpublished records from the fire guard station. Calculated solar radiation at the fire guard station was calibrated to measured data at Lewiston, Idaho, obtained from Cinquemani et al. (1978). Table I.8 contains the transposed data.

Validation. Some measured minimum-maximum water temperature data were available from different sources, but no single source had sufficient measured data to be considered truly reliable for average mean daily water temperatures or average diurnal fluctuations. Nor did any single source have more than just a few months of data. For example, D. W. Kelley and Associates had min-max thermometers at six locations for just a few days during August, 1980. However, a comparison of these measured versus predicted values was used to see if the predictions seemed to be reasonable. Table I.9 gives the comparisons for both the average mean daily water temperatures and the average diurnal fluctuations. The measured average mean daily values are simply the arithmetic averages of the average minimum and average maximum values over the time period available. The average diurnal fluctuations are half the difference between the average maximum and minimum values. A more complete validation study of the model with a more comprehensive set of published data was done on the Upper Colorado River basin (Theurer and Voos 1982).

Table I.7. Diversions and returns along mainstem Tucannon River.

Node type	Distance (m)	Flow (cms)					Remarks
		May	June	July	August	September	
D	74.2	0.368	0.368	0.368	0.368	0.368	at Four Lakes diversion
R	74.2	0.184	0.184	0.184	0.184	0.184	at Four Lakes return
D	68.2	0.113	0.113	0.113	0.113	0.113	at Deer Lake diversion
R	65.6	0.057	0.057	0.057	0.057	0.057	at Deer Lake return
D	64.0	0.425	0.425	0.425	0.425	0.425	at Rainbow Lake diversion
R	64.0	0.425	0.425	0.425	0.425	0.425	at Rainbow Lake return
D	51.4	0.028	0.028	0.028	0.028	0.014	at Bridge No. 13 diversion
D	47.0	0.028	0.028	0.028	0.028	0.014	at Bridge No. 11 diversion
D	41.7	0.028	0.028	0.028	0.028	0.014	at Marengo Bridge diversion
D	35.6	0.028	0.028	0.028	0.028	0.014	at King's Grade Bridge diversion
D	23.5	0.028	0.028	0.028	0.028	0.014	at DeRue's diversion
D	21.5	0.028	0.028	0.028	0.028	0.014	at Krouse's diversion
D	15.1	0.035	0.035	0.035	0.035	0.018	at Fletcher's diversion
D	13.4	0.035	0.035	0.035	0.035	0.018	at Starbuck diversion
D	9.0	0.142	0.142	0.142	0.142	0.071	at hog farmers' diversion

Table I.8. Meteorological data transposed to Forest Service fire guard station. Latitude = 46 15', elevation = 789 m, mean annual air temperature = 8.38 C.

Year	Month	Air temperature (C)	Relative humidity (dec.)	Wind speed (m/s)	Possible sunshine (dec.)	Solar rad. at grnd. ($J/m^2/sec$)
1980	May	11.89	0.61	2.55	0.53	--
	June	13.83	0.56	2.46	0.56	--
	July	20.11	0.63	2.24	0.75	--
	August	17.28	0.52	2.08	0.79	--
	September	14.94	0.58	2.49	0.66	--
1981	May	11.10	0.61	2.55	0.45	--
	June	13.90	0.56	2.46	0.51	--
	July	18.57	0.63	2.24	0.87	--
	August	21.68	0.52	2.08	0.86	--
	September	16.29	0.58	2.49	0.73	--
Normal	May	11.83	0.61	2.55	0.66	239.6
	June	15.67	0.55	2.46	0.72	264.7
	July	20.33	0.46	2.24	0.85	305.4
	August	19.22	0.51	2.08	0.82	247.4
	September	14.83	0.56	2.49	0.73	173.7

Table I.9. Validation data.

Stream name	Distance (km)	Year	Month	Average mean daily water temperature (C) Observed	Average mean daily water temperature (C) Predicted	Average diurnal fluctuation (C) Observed	Average diurnal fluctuation (C) Predicted	Remarks
Tucannon River	91.1	1980	May	--	5.8	--	0.7	above Sheep Creek confluence
			June	--	6.2	--	0.9	
			July	--	9.7	--	1.4	observed temperatures were
			August	--	8.2	--	1.5	unpublished data provided
			September	--	7.4	--	1.1	by Ernie Felix, Hydrologist, USFS
		1981	May	--	5.7	--	0.8	
			June	8.3	6.2	1.7	0.9	min-max data, 6/9-6/30, 1981
			July	8.9	9.2	1.7	1.5	min-max data, 7/1-7/25, 1981
			August	--	10.8	--	1.7	
			September	8.3	8.2	1.1	1.2	min-max data, 9/2-9/30, 1981
		Normal	May	--	5.8	--	0.8	
			June	--	6.6	--	1.1	
			July	--	9.0	--	1.7	
			August	--	9.2	--	1.6	
			September	--	7.2	--	1.2	
Panjab Creek	83.9	1980	May	--	6.8	--	3.8	at Tucannon River confluence
			June	--	7.4	--	4.4	
			July	--	11.2	--	7.0	observed temperatures were
			August	--	10.0	--	7.2	unpublished data provided
			September	--	8.4	--	5.4	by Ernie Felix, Hydrologist, USFS
		1981	May	--	6.9	--	3.8	
			June	11.7	7.4	1.7	4.3	min-max data, 6/9-6/30, 1981
			July	10.6	11.3	2.8	7.7	min-max data, 7/1-7/31, 1981
			August	11.4	12.5	3.1	8.0	min-max data, 8/1-8/22, 1981
			September	9.7	9.2	1.9	6.0	min-max data, 9/2-9/30, 1981
		Normal	May	--	6.9	--	4.4	
			June	--	7.8	--	5.2	
			July	--	11.1	--	7.8	
			August	--	10.9	--	7.6	
			September	--	8.3	--	5.7	

Table I.9. (continued)

Stream name	Distance (km)	Year	Month	Average mean daily water temperature (C) Observed	Average mean daily water temperature (C) Predicted	Average diurnal fluctuation (C) Observed	Average diurnal fluctuation (C) Predicted	Remarks
Tucannon River	83.9	1980	May	--	6.7	--	1.7	below Panjab Creek junction
			June	--	7.3	--	2.0	
			July	--	11.2	--	3.3	observed temperatures were
			August	--	9.7	--	3.4	unpublished data provided
			September	--	8.4	--	2.5	by Ernie Felix, Hydrologist, USFS
		1981	May	--	6.7	--	1.8	
			June	8.3	7.3	1.7	2.0	min-max data, 6/9-6/30, 1981
			July	9.4	10.9	2.2	3.6	min-max data, 7/1-7/31,1981
			August	6.1	12.5	2.2	3.8	min-max data, 8/1-8/21, 1981
			September	9.4	9.3	1.7	2.8	min-max data, 9/2-9/20, 1981
		Normal	May	--	6.7	--	2.0	
			June	--	7.7	--	2.4	
			July	--	10.7	--	3.7	
			August	--	10.7	--	3.6	
			September	--	8.3	--	2.6	
Ltl. Tuc. Riv.	80.5	1980	May	--	6.5	--	1.0	above Tucannon River confluence
			June	--	6.7	--	1.2	
			July	--	8.5	--	1.8	observed temperatures were
			August	--	7.8	--	1.9	unpublished data provided
			September	--	7.3	--	1.5	by Ernie Felix, Hydrologist, USFS
		1981	May	--	6.5	--	1.0	
			June	8.9	6.7	1.1	1.2	min-max data, 6/9-6/30, 1981
			July	11.1	8.3	2.2	2.0	min-max data, 7/1-7/31, 1981
			August	12.2	9.4	2.2	2.2	min-max data, 8/1-8/22, 1981
			September	8.1	7.8	1.4	1.6	min-max data, 9/2-9/30, 1981
		Normal	May	--	6.5	--	1.2	
			June	--	6.9	--	1.4	
			July	--	8.2	--	2.1	
			August	--	8.4	--	2.0	
			September	--	7.2	--	1.5	

Table I.9. (continued)

Stream name	Distance (km)	Year	Month	Average mean daily water temperature (C) Observed	Predicted	Average diurnal fluctuation (C) Observed	Predicted	Remarks
Tucannon River	80.5	1980	May	--	7.0	--	1.8	below Ltl. Tuc. River junction
			June	--	7.7	--	2.3	
			July	--	12.2	--	3.8	observed temperatures were unpublished data provided by Ernie Felix, Hydrologist, USFS
			August	--	10.5	--	3.8	
			September	--	9.0	--	2.7	
		1981	May	--	7.1	--	1.9	
			June	12.2	7.8	1.7	2.2	min-max data, 6/9-6/30, 1981
			July	11.7	11.9	2.8	4.2	min-max data, 7/1-7/31, 1981
			August	12.8	13.5	2.8	4.2	min-max data, 8/1-8/22, 1981
			September	7.8	10.0	1.7	3.0	min-max data, 9/2-9/30, 1981
		Normal	May	--	7.1	--	2.1	
			June	--	8.2	--	2.7	
			July	--	11.7	--	4.3	
			August	--	11.6	--	4.0	
			September	--	8.8	--	2.8	
Tucannon River	70.2	1980	May	--	7.9	--	1.0	National Forest boundary
			June	--	9.0	--	1.3	
			July	--	14.7	--	1.9	observed temperatures were unpublished data provided by Ernie Felix, Hydrologist, USFS
			August	--	12.4	--	2.0	
			September	--	10.5	--	1.6	
		1981	May	--	8.0	--	1.1	
			June	--	9.0	--	1.2	
			July	14.7	14.3	4.2	2.1	min-max data, 7/8-7/31, 1981
			August	15.3	15.8	4.2	2.2	min-max data, 8/1-8/5, 1981
			September	10.0	11.6	2.8	1.7	min-max data, 9/2-9/30, 1981
		Normal	May	--	8.0	--	1.1	
			June	--	9.7	--	1.4	
			July	--	14.0	--	2.2	
			August	--	13.7	--	2.1	
			September	--	10.3	--	1.7	

Table I.9. (continued)

Stream name	Distance (km)	Year	Month	Average mean daily water temperature (C)		Average diurnal fluctuation (C)		Remarks
				Observed	Predicted	Observed	Predicted	
Tucannon River	62.4	1980	May	8.2	8.8	1.9	1.4	State fish hatchery
			June	10.6	10.3	2.4	1.8	
			July	14.8	17.2	3.3	2.7	
			August	14.0	14.4	3.1	2.9	
			September	12.1	11.9	2.2	2.3	
		1981	May	9.8	9.0	--	1.5	observed temperatures were unpublished hourly data furnished by State fish hatchery personnel
			June	12.1	10.3	--	1.7	
			July	15.9	16.7	--	3.0	
			August	17.2	18.1	--	3.1	
			September	13.4	13.2	--	2.5	
		Normal	May	--	9.0	--	1.6	
			June	--	11.2	--	2.0	
			July	--	16.4	--	3.1	
			August	--	15.8	--	3.0	
			September	--	11.7	--	2.4	
Tucannon River	49.6	1980	May	--	10.0	--	2.2	Bridge No. 12
			June	--	11.9	--	2.7	
			July	--	19.8	--	3.9	
			August	16.2	16.4	4.3	4.5	min-max data, 8/16-8/25, 1980
			September	--	13.3	--	3.4	
		1981	May	--	10.2	--	2.4	observed temperatures were unpublished data furnished by D. W. Kelley & Assoc.
			June	--	11.9	--	2.6	
			July	--	19.3	--	4.4	
			August	--	20.2	--	4.6	
			September	--	14.7	--	3.7	
		Normal	May	--	10.2	--	2.5	
			June	--	13.1	--	3.1	
			July	--	18.9	--	4.5	
			August	--	17.9	--	4.5	
			September	--	13.1	--	3.6	

Table I.9. (continued)

Stream name	Distance (KM)	Year	Month	Average mean daily water temperature (C)		Average diurnal fluctuation (C)		Remarks
				Observed	Predicted	Observed	Predicted	
Tucannon River	47.0	1980	May	--	10.2	--	2.2	Bridge No. 11
			June	--	12.3	--	2.7	
			July	--	20.2	--	3.8	
			August	17.8	16.8	4.6	4.4	min-max data, 8/12-8/18, 1980
			September	--	13.6	--	3.3	
		1981	May	--	10.5	--	2.4	observed temperatures were unpublished data furnished by D. W. Kelley & Assoc.
			June	--	12.3	--	2.6	
			July	--	19.8	--	4.3	
			August	--	20.5	--	4.5	
			September	--	14.9	--	3.7	
		Normal	May	--	10.5	--	2.5	
			June	--	13.5	--	3.0	
			July	--	19.4	--	4.4	
			August	--	18.3	--	4.4	
			September	--	13.4	--	3.5	
Tucannon River	45.6	1980	May	--	10.3	--	1.5	Bridge No. 10
			June	--	12.4	--	1.8	
			July	--	20.3	--	2.7	
			August	17.5	16.8	4.2	3.1	min-max data, 8/12-8/25, 1980
			September	--	13.6	--	2.4	
		1981	May	--	10.6	--	1.6	observed temperatures were unpublished data furnished by D. W. Kelley & Assoc.
			June	--	12.4	--	1.8	
			July	--	19.8	--	3.0	
			August	--	20.4	--	3.2	
			September	--	15.0	--	2.7	
		Normal	May	--	10.6	--	1.7	
			June	--	13.6	--	2.1	
			July	--	19.4	--	3.1	
			August	--	18.3	--	3.2	
			September	--	13.4	--	2.5	

Table I.9. (continued)

Stream name	Distance (km)	Year	Month	Average mean daily water temperature (C) Observed	Predicted	Average diurnal fluctuation (C) Observed	Predicted	Remarks
Tucannon River	42.8	1980	May	--	10.5	--	1.4	Bridge No. 9
			June	--	12.6	--	1.8	
			July	--	20.4	--	2.7	
			August	18.6	16.9	3.9	3.1	min-max data, 8/12-8/18, 1980
			September	--	13.7	--	2.4	
		1981	May	--	10.7	--	1.6	observed temperatures were unpublished data furnished by D. W. Kelley & Assoc.
			June	--	12.6	--	1.7	
			July	--	19.9	--	3.0	
			August	--	20.4	--	3.2	
			September	--	15.0	--	2.7	
		Normal	May	--	10.8	--	1.7	
			June	--	13.8	--	2.0	
			July	--	19.5	--	3.1	
			August	--	18.3	--	3.1	
			September	--	13.5	--	2.5	
Tucannon River	42.2	1980	May	--	10.5	--	2.7	Marengo Bridge
			June	--	12.6	--	3.2	
			July	--	20.4	--	4.2	
			August	16.5	17.0	4.5	4.8	min-max, 8/21-8/25, 1980
			September	--	13.8	--	3.8	
		1981	May	--	10.8	--	2.8	observed temperatures were unpublished data furnished by D. W. Kelley & Assoc.
			June	--	12.6	--	3.1	
			July	--	20.0	--	4.7	
			August	--	20.5	--	4.9	
			September	--	15.1	--	4.1	
		Normal	May	--	10.8	--	3.1	
			June	--	13.9	--	3.6	
			July	--	19.6	--	4.8	
			August	--	18.4	--	4.9	
			September	--	13.6	--	4.0	

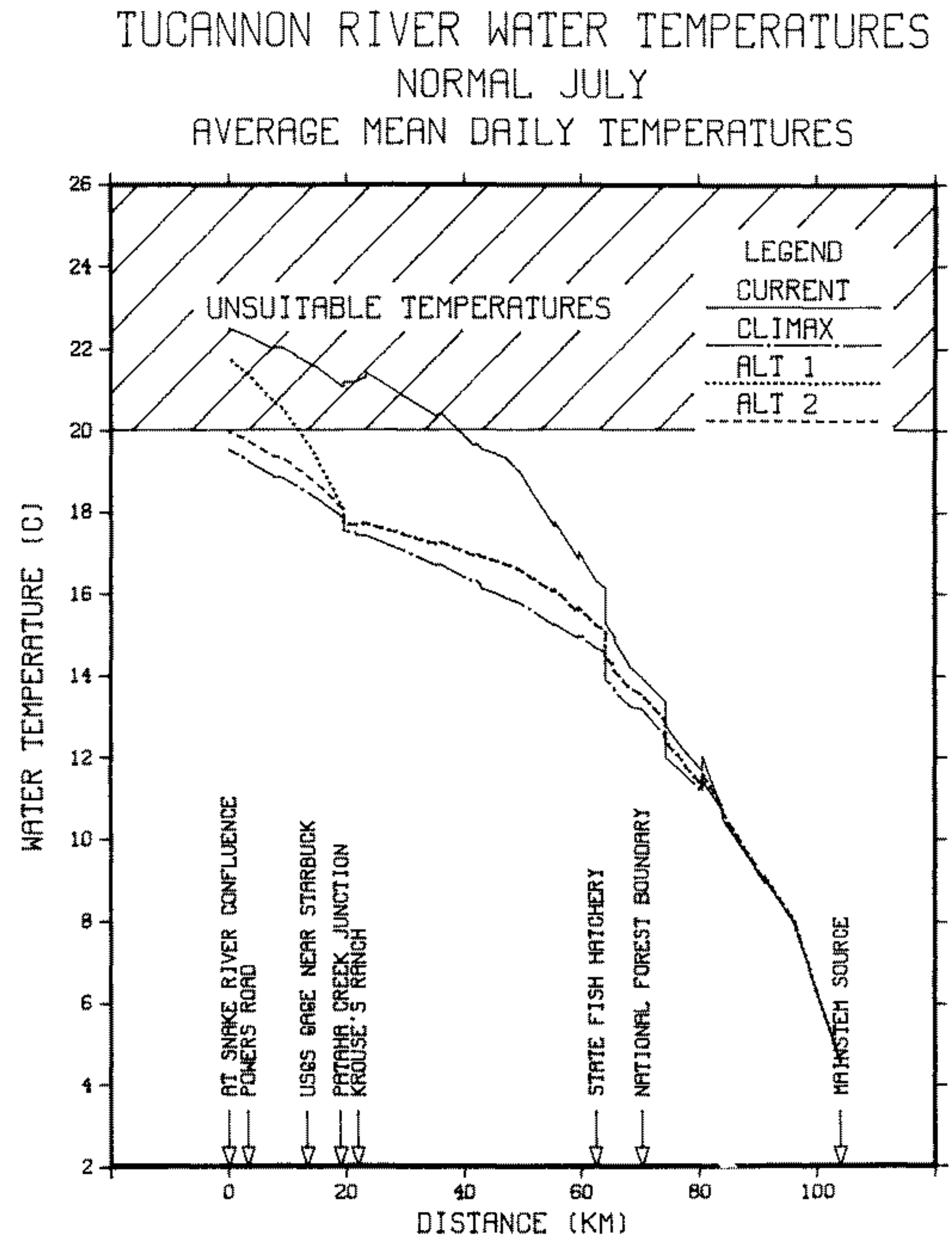
Table I.9. (concluded)

Stream name	Distance (km)	Year	Month	Average mean daily water temperature (C)		Average diurnal fluctuation (C)		Remarks
				Observed	Predicted	Observed	Predicted	
Tucannon River	36.1	1980	May	--	11.1	--	2.2	King's Grade Bridge
			June	--	13.3	--	2.7	
			July	--	21.2	--	3.9	
			August	17.8	17.6	4.8	4.4	min-max data, 8/21/80
			September	--	14.2	--	3.3	
		1981	May	--	11.4	--	2.4	observed temperatures were unpublished data furnished by D. W. Kelley & Assoc.
			June	--	13.3	--	2.6	
			July	--	20.7	--	4.3	
			August	--	21.1	--	4.5	
			September	--	15.5	--	3.6	
		Normal	May	--	11.4	--	2.6	
			June	--	14.7	--	3.1	
			July	--	20.3	--	4.4	
			August	--	19.0	--	4.4	
			September	--	14.0	--	3.4	

Longitudinal temperature profiles. Longitudinal temperature profiles are plots of water temperature versus distance for a given set of meteorological, hydrological, and stream geometry conditions. All 5 months of 1980, 1981, and the normals were studied. Only the normal water temperatures for July are shown in this paper because July had the highest water temperatures, and the normals represent the 50% chance. Therefore, the normal July water temperatures can be interpreted to mean that actual July water temperatures can be expected to exceed the predicted values 1 year out of 2. Figures 1.3 and 1.4 are the longitudinal temperature profiles of the mainstem Tucannon River for the average mean daily and average maximum daily water temperatures for the normal July time period. (The maximum is equal to the mean plus the diurnal fluctuation.)

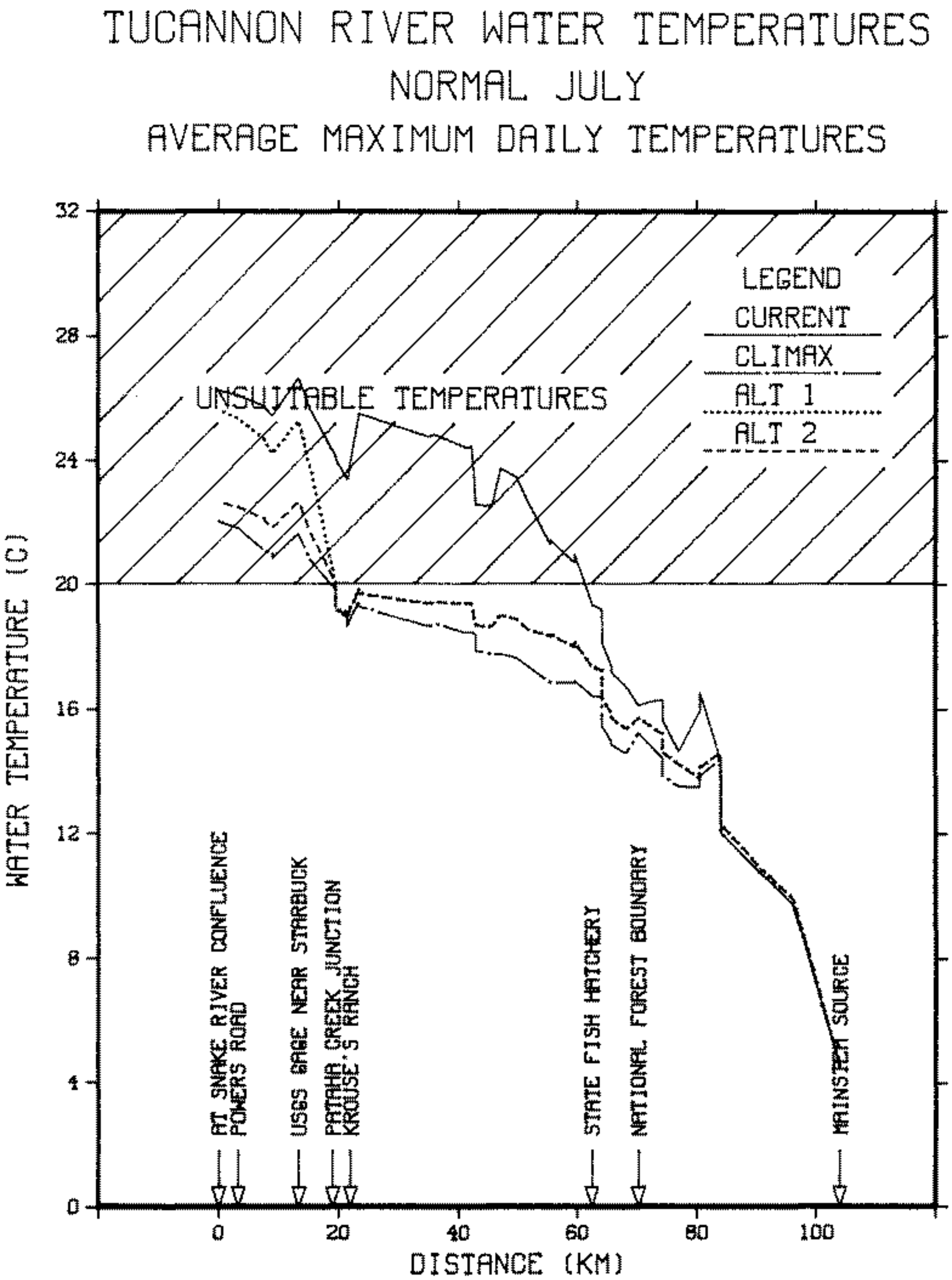
The longitudinal temperature profiles for each of the four stream conditions are shown. It is easily seen that the existing condition in the lower reaches is too hot (greater than 20 C) for salmonid rearing habitat and that temperatures under the climax condition are good to excellent. Alternative 1 would restore most, and Alternative 2 would restore all, of the aquatic habitat in the river to nearly the original (climax) thermal conditions. The difference of approximately 0.5 C between Alternative 2 and the climax conditions at the lower end of the river is due to the channel morphology change or residual widening, which may continue if not treated. The wider the stream, the higher the temperature. Restoring the riparian vegetation would help stabilize the stream, but additional land treatment measures also would be needed to reduce the sediment load that is contributing to the instability.

Effects of temperature on salmonids. The maximum temperature that fish can tolerate varies with the species, life-stage (egg, fry, fingerling, or adult), prior acclimatization, oxygen availability, and the synergistic effects of pollutants. Lethal temperatures for adult salmon and steelhead range from approximately 23 to 25 C. Given the opportunity, juvenile and adult salmonids occupy water that is 13 to 18 C. Salmonid eggs incubated in water above 11 to 12 C suffer abnormal mortality (McKee and Wolf 1963).



Curves are for the four stream conditions:
Existing -- 1980 riparian vegetation and stream morphology.
Climax -- Climax riparian vegetation and stream morphology to the Snake R.
Alt. 1 -- Climax riparian vegetation to Pataha Cr., 1980 riparian vegetation below Pataha, and 1980 stream morphology to the Snake R.
Alt. 2 -- Climax riparian vegetation and 1980 stream morphology to the Snake R.

Figure I.3. Longitudinal average mean daily temperature profile.



Curves are for the four stream conditions:
Existing -- 1980 riparian vegetation and stream morphology.
Climax -- Climax riparian vegetation and stream morphology to the Snake R.
Alt. 1 -- Climax riparian vegetation to Pataha Cr., 1980 riparian vegetation below Pataha, and 1980 stream morphology to the Snake R.
Alt. 2 -- Climax riparian vegetation and 1980 stream morphology to the Snake R.

Figure I.4. Longitudinal maximum daily temperature profile.

Elevated water temperatures result in a reduced growth rate and/or indirect mortality associated with the following phenomenon:

(1) Higher temperatures diminish the solubility of dissolved oxygen and, thus, decrease its availability;

(2) Elevated temperatures increase the metabolism, respiration, and oxygen demand of fish and other aquatic life, approximately doubling respiration with a 10 C rise in temperature. Hence, the demand for oxygen may exceed the supply;

(3) The toxicity of many substances is intensified as the temperature rises;

(4) Higher temperatures increase the rate of organic decomposition, creating an increased oxygen demand at an already decreased oxygen level; and

(5) Many fish disease organisms proliferate at higher temperatures, and fish are more susceptible to disease when stressed by higher temperatures.

The juvenile life stage was selected as the representative life stage for this example because it is present all year. An upper limit of 20 C was considered lethal, and the hottest month was July. When the water temperatures rise, the juveniles most likely move upstream to cooler waters, where the carrying capacity of the reduced habitat area limit the number surviving. The actual carrying capacity of the Tucannon River was determined by fish count.

Salmonid population analysis. In August, 1980, juvenile steelhead and salmon populations were estimated in several pools, glides, and riffles in the Tucannon River. The estimates were based on diminishing catches of fish (Hayne 1949), using a large electro-fishing unit, in a specific reach of stream. The biomass of each species was estimated by measuring the mass of a representative number of each species, using volumetric displacement, and multiplying the mean biomass by the total number of that species estimated to be in the sampled reach.

During the summer of 1980, the quality and quantity of rearing habitat for juvenile steelhead and chinook salmon in the Tucannon River also were assessed (Kelley and Associates 1982). Habitat quality was rated for pools, riffles, and glides in 18 representative stream reaches totaling 31.5 km. Variables used to estimate the quality of rearing habitat were water velocity, substrate size, water depth, instream cover, and shade. Some ratings were adjusted after the analysis of electrofishing data revealed that higher velocities reduced habitat quality more than previously estimated.

Habitat quality ratings and the width and length of each pool, riffle, and glide were used to calculate "rearing indices":

$$\text{Rearing Index (RI)} = \frac{\text{habitat rating x area rated}}{\text{length of reach}}$$

The rearing index is an expression of the quality of rearing habitat per linear meter of stream (Kelley and Associates 1982).

Population estimates for yearling steelhead and young-of-the-year chinook were compared to calculated rearing indices. The number of yearling steelhead and young-of-the-year chinook salmon were highly correlated ($r^2 = 0.89$ for both species) with the rearing indices for ten reaches of stream where population estimates were available. The numbers of yearling steelhead and young-of-the-year chinook salmon per linear meter of stream in the Tucannon were estimated as follows:

$$\text{yearling steelhead per linear meter} = 0.230 + 0.0262 \text{ RI}$$
$$\text{young-of-the-year chinook per linear meter} = 0.033 + 0.0459 \text{ RI}$$

Using these equations and the known length of stream, the numbers of yearling steelhead and young-of-the-year chinook in the entire Tucannon River in 1980 were estimated. These equations also were used to estimate the rearing potential for these fish in two major downstream reaches where current water temperatures preclude salmonid rearing (Table I.10). To reach the potential of these reaches, Alternatives 1 and 2 assumed sufficient numbers of spawning fish to adequately seed the stream and no other physical changes in habitat. Suitable water temperatures (less than 20 C) downstream to Pataha Creek would nearly double the salmonid-rearing potential, and suitable temperatures downstream to the mouth of the Tucannon River could increase the juvenile-rearing potential by at least two and one-half times. Table I.11 shows the conversion of juvenile to returning spawners, according to published U.S. Fish and Wildlife Service (1982) data.

Table I.10. Estimated juvenile fish production in the Tucannon River, Washington.

Alternative	Yearling steelhead	Young-of-the-year chinook salmon
Current conditions (1980)	111,000	170,000
Alternative 1 suitable temperatures to Pataha Creek	206,000	314,000
Alternative 2 suitable temperatures to mouth of Tucannon River	279,000	430,000

Table I.11. Estimated adult fish returns to Tucannon River, Washington.[a]

Alternative	Steelhead	Chinook salmon
Current conditions (1980)	1,832	884
Alternative 1 suitable temperatures to Pataha Creek	3,399	1,633
Alternative 2 suitable temperatures to mouth of Tucannon River	4,604	2,236

[a]Based on U.S. Fish and Wildlife Service (1982) estimate of 1.65 and 0.52% survival from Tucannon River smolt to returning adult for steelhead and spring chinook, respectively.

The number of adult fish returning to the Tucannon River was estimated using survival rates developed by the U.S. Fish and Wildlife Service (1982) (1.65% for steelhead and 0.52% for chinook). These rates of survival were applied to the estimates of juvenile fish production in 1980, as well as the predicted production with the two thermal improvement alternatives. Assuming adequate escapement, Alternative 1 would result in nearly twice as many adult steelhead and chinook salmon entering the Tucannon River compared to current conditions; Alternative 2 would result in two and one-half times as many adult fish entering the river.

Economic analysis. The restoration of salmon and steelhead resources in the Tucannon River resulting from improvements in aquatic habitat also was evaluated from an economic standpoint. The predicted restoration of fish numbers were valued, as reported by Meyer (1982) and Meyer et al. (1983). Meyer and Meyer et al. followed the procedures recommended by the U.S. Water Resources Council (1983). These procedures combine commercial and sport values with catch/escapement data to estimate the net value per spawner for each species. The net value estimated per returning spawner was $244 for steelhead and $290 for chinook salmon. These values were applied to the restored number of spawners predicted from improved aquatic habitat resulting from two levels of treatment in the Tucannon River. The first treatment level would provide adequate thermal conditions for rearing in Tucannon River downstream to its confluence with Pataha Creek. The second alternative would provide adequate thermal conditions to the mouth of the Tucannon River.

Table I.12 displays the number of returning spawners, restored spawners, and their annual monetary benefit. The number of spawners and annual benefits represent annual returns after optimum thermal conditions have been obtained. Approximately 20 years would be required before revegetation would fully control thermal conditions for the stream reaches described for Alternatives 1 and 2 (Fig. I.5).

monetary value per escaping spawner.

Alternative	Steelhead			Chinook Salmon			Total annual benefit ($)
	Returned spawners	Restored spawner	Annual benefit[a] ($)	Returned spawners	Restored spawner	Annual benefit[b] ($)	
Future W/O	1,832			884			
1	3,399	1,567	382,348	1,633	749	217,210	599,558
2	4,604	2,772	676,368	2,236	1,352	392,080	1,068,448

[a]Based on $244 per spawner.

[b]Based on $290 per spawner.

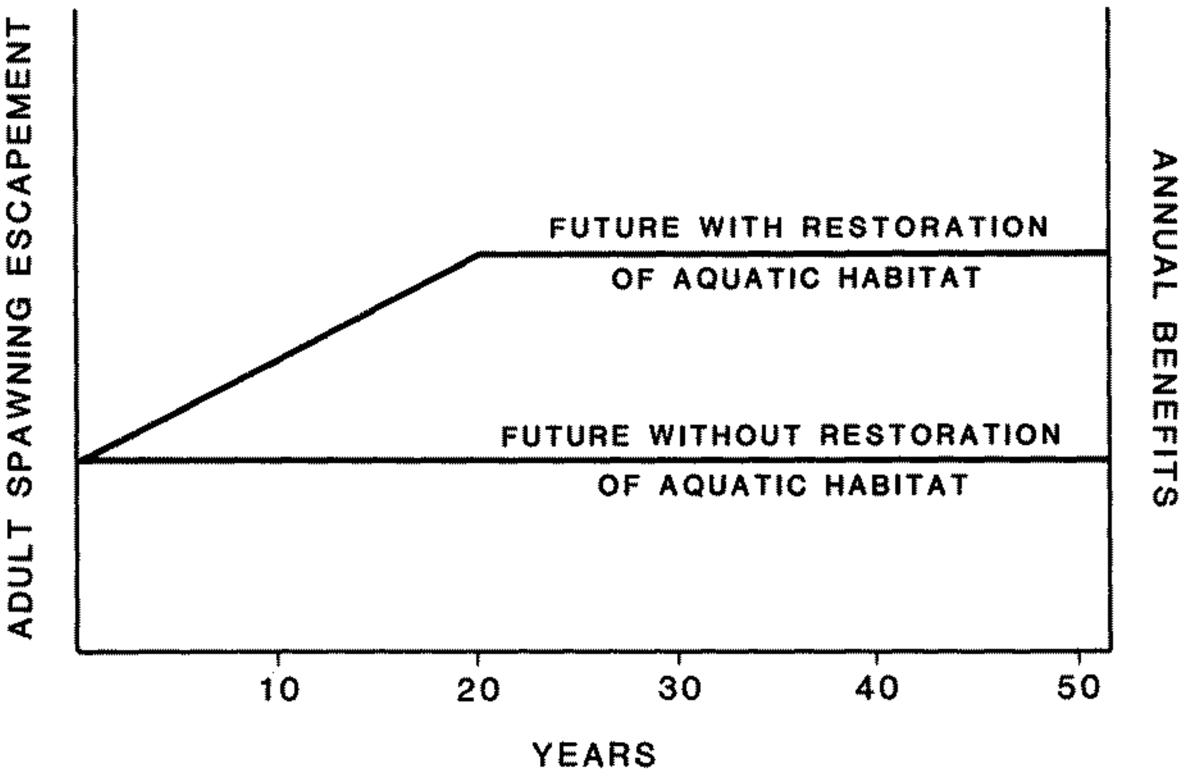


Figure I.5. Distribution of predicted fishery enhancement resulting from restoration of aquatic habitat.

Table I.13 shows the present worth and average annual benefits for the two alternatives proposed to control thermal conditions on the Tucannon River. These values only represent an estimate of the economic potential of improving aquatic habitat. However, they suggest that the return from investment in improving thermal conditions of the Tucannon River could be significant.

Table I.13. Present worth and average annual benefits.[a]

Alternative	Steelhead		Chinook Salmon		Total	
	Present worth ($)	Ave. annual benefit ($)	Present worth ($)	Ave. annual benefit ($)	Present worth ($)	Ave. annual benefit ($)
1	2,485,560	200,262	1,412,034	113,768	3,897,594	314,030
2	4,396,920	354,260	2,548,826	205,359	6,945,746	559,619

[a]Based on 50 years at 7-7/8% interest.

The restoration of the riparian vegetation according to Alternative 2 would require a 10 m buffer zone on each side of the stream. This would involve easements of 140 ha, valued at approximately $5,000/ha ($2,000/acre), for a total of $700,000, if purchased. The estimate for planting trees is approximately $800,000.

Summary. This analysis, which relates riparian vegetation and water temperature to salmonid habitat, demonstrates the efficacy of multidisciplinary modeling efforts. The economic results clearly indicate the value and feasibility of restoring riparian vegetation. The total cost for restoring the entire thermal regime would be less than $1.5 million, contrasted to the benefits of $6.9 million due to increased numbers of salmonids (Alternative 2). A more comprehensive economic analysis of aquatic resources throughout the country may show equally dramatic results (Theurer 1983).

Recommendations. The change in the temperature regime resulting from the loss of riparian vegetation is sufficient to explain the reduction in salmonid population in the Tucannon River. However, there also is a secondary reason: an increase in fine sediment in the bed material. The gravel substrate in the Tucannon River is used for spawning beds. When the amount of fines in the gravel interstices increases, the water flow through the gravel is reduced. At some point, the oxygen available to the eggs becomes limiting, and toxic metabolites surrounding the embryos increase, resulting in higher mortality. In addition, the surviving fry may have a difficult time emerging from the gravel. Therefore, the affect of the sediment on the aquatic habitat needs to be quantified and its source identified (upland and/or streambank erosion).

Fifty-one percent of the watershed is used for agriculture, most of which is nonirrigated. The average annual erosion rate is 14 tons per acre per year. Proper soil and water conservation practices can reduce this rate to 3 tons per acre per year.

The potential 1.1 million average annual dollars (Table I.12) resulting from improved thermal aquatic habitat, plus additional benefits in terms of increased crop production and aquatic habitat resulting from decreased erosion, would support both a land treatment program and the restoration of the riparian vegetation. A more comprehensive analysis, incorporating the effects of sediment on aquatic habitat, is expected to show considerably more potential for increasing the total carrying capacity of the Tucannon River. This would result in a worth significantly greater than the value obtained by only improving temperature.

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INSTREAM WATER TEMPERATURE MODEL
Part II. Physical Processes and Math Models

Fish and Wildlife Service

U.S. Department of the Interior

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CONTENTS. (concluded)

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PART II. PHYSICAL PROCESSES AND MATH MODELS

INTRODUCTION

Part II discusses each of the physical processes that affect instream water temperatures and their mathematical descriptions, so that engineers and scientists can understand the behavior of the model and determine the applicability of the model, the utility of linking the model with other models, and the validity of results.

The instream water temperature model incorporates: (1) a complete solar model that includes both topographic and riparian vegetation shade; (2) an adiabatic meteorological correction model to account for the change in air temperature, relative humidity, and atmospheric pressure as a function of elevation; (3) a complete set of heat flux components to account for all significant heat sources; (4) a heat transport model to determine longitudinal water temperature changes; (5) regression models to smooth or complete known water temperature data sets at measured points for starting or interior validation/calibration temperatures; (6) a flow mixing model at tributary junctions; and (7) calibration equations and tips to help eliminate bias and/or reduce the probable errors at interior calibration nodes.

Further information concerning the various model components can be found in the following sources:

Solar radiation and subsequent alternatives - Tennessee Valley Authority 1972

Heat flux components - Tennessee Valley Authority 1972

Heat transport - Grenney and Kraszewski 1981

Shade - Quigley 1981.

Information concerning a fully dynamic flow and water temperature model may be found in Johnson et al. (1979). However, the fully dynamic model is not a network model and has all the execution difficulties associated with dynamic flow models.

SOLAR RADIATION

The solar radiation model has four parts: (1) extra-terrestrial radiation; (2) correction for atmospheric conditions; (3) correction for cloud cover; and (4) correction for reflection from the water surface. The extra-terrestrial radiation, when corrected for both the atmosphere and cloud cover, predicts the average daily solar radiation received at the ground on a horizontal surface of unit area. Therefore, it is the total amount of solar energy per unit area that projects onto a level surface in a 24-hour period. It is expressed as a constant rate of heat energy flux over a 24-hour period even though there is no sunshine at night and the actual solar radiation varies from zero at sunrise and sunset to maximum intensity at solar noon.

Extra-Terrestrial Radiation

The extra-terrestrial radiation at a site is a function of the latitude, general topographic features, and time of year. The general topographic features affect the actual time of sunrise and sunset at a site. Therefore, the effect of solar shading due to hills and canyon walls can be quantified. The time of year directly predicts the angle of the sun above or below the equator (declination) and the distance between the earth and the sun (orbital position). The latitude is a measure of the angle between horizontal surfaces along the same longitude at the equator and the site.

The extra-terrestrial solar radiation equation is:

$$H_{sx,i} = (q_s/\pi) \{[(1 + e \cos\theta_i)^2/(1-e^2)]\} \{[h_{s,i}(\sin\phi \sin\delta_i)] + [\sin h_{s,i}(\cos\phi \cos\delta_i)]\} \qquad \text{II(1)}$$

where q_s ≡ solar constant = 1377 ($J/m^2/sec$)

e ≡ orbital eccentricity = 0.0167238 (decimal)

θ_i ≡ earth orbit position about the sun (radians)

ϕ ≡ site latitude for day i (radians)

δ_i ≡ sun declination for day i (radians)

$h_{s,i}$ ≡ sunrise/sunset hour angle for day i (radians)

$H_{sx,i}$ ≡ average daily extra-terrestrial solar radiation for day i ($J/m^2/sec$)

The extra-terrestrial solar radiation can be averaged over any time period:

$$\overline{H}_{sx} = [\sum_{i=n}^{N} H_{sx,i}]/[N-n+1] \qquad \text{II(2)}$$

where $H_{sx,i}$ ≡ extra-terrestrial solar radiation for day i ($J/m^2/sec$)

N ≡ last day in time period (Julian days)

n ≡ first day in time period (Julian days)

i ≡ day counter (Julian day)

$\overline{H}_{sx}$ ≡ extra-terrestrial solar radiation averaged over time period n to N ($J/m^2/sec$)

The earth orbit position and sun declination as a function of the day of the year are:

$$\theta_i = [(2\pi/365)\ (D_i-2)] \qquad \text{II(3)}$$

$$\delta_i = 0.40928 \cos [(2\pi/365)\ (172-D_i)] \qquad \text{II(4)}$$

where D_i ≡ day of year (Julian days) D_i=1 for January 1 and D_i=365 for December 31

θ_i ≡ earth orbit position for day i (radians)

δ_i ≡ sun declination for day i (radians)

The sunrise/sunset hour angle is a measure of time, expressed as an angle, between solar noon and sunrise/sunset. Solar noon is when the sun is at its zenith. The time from sunrise to noon is equal to the time from noon to sunset only for symetrical topographic situations. However, for simplicity, the following equation assumes that an average of the solar attitudes at sunrise/sunset is used. Therefore, the sunrise/sunset hour angle (see Fig. II.1) is:

$$h_{s,i} = \arccos \{[\sin\alpha_s-(\sin\phi \ \sin\delta_i)]/[\cos\phi \ \cos\delta_i]\} \qquad \text{II(5)}$$

$$\bar{h}_s = [\sum_{i=n}^{N} h_{s,i}]/[N-n + 1] \qquad \text{II(6)}$$

where ϕ ≡ site latitude (radians)

δ_i ≡ sun declination for day i (radians)

α_s ≡ average solar altitude at sunrise/sunset (radians) $\alpha_s = 0$ for flat terrain, $\alpha_s > 0$ for hilly or canyon terrain

$h_{s,i}$ ≡ sunrise/sunset hour angle for day i (radians)

$\bar{h}_s$ ≡ average sunrise/sunset hour angle over the time period n to N (radians)

n ≡ first day of time period (Julian days)

N ≡ last day of time period (Julian days)

i ≡ day counter (Julian day)

It is possible for some sites to be completely shaded from the sun during winter months. This is why snow often lasts on the north slopes of hillsides. Therefore, certain restrictions are imposed on α_s; i.e., $\alpha_s \leq (\pi/2) - \phi + \delta_i$.

The average solar altitude at sunrise/sunset is a measure of the obstruction of topographic features. It is determined by measuring the average angle from the horizon to the point where the sun rises and sets. The shade model accounts for local sunrise and sunset independently.

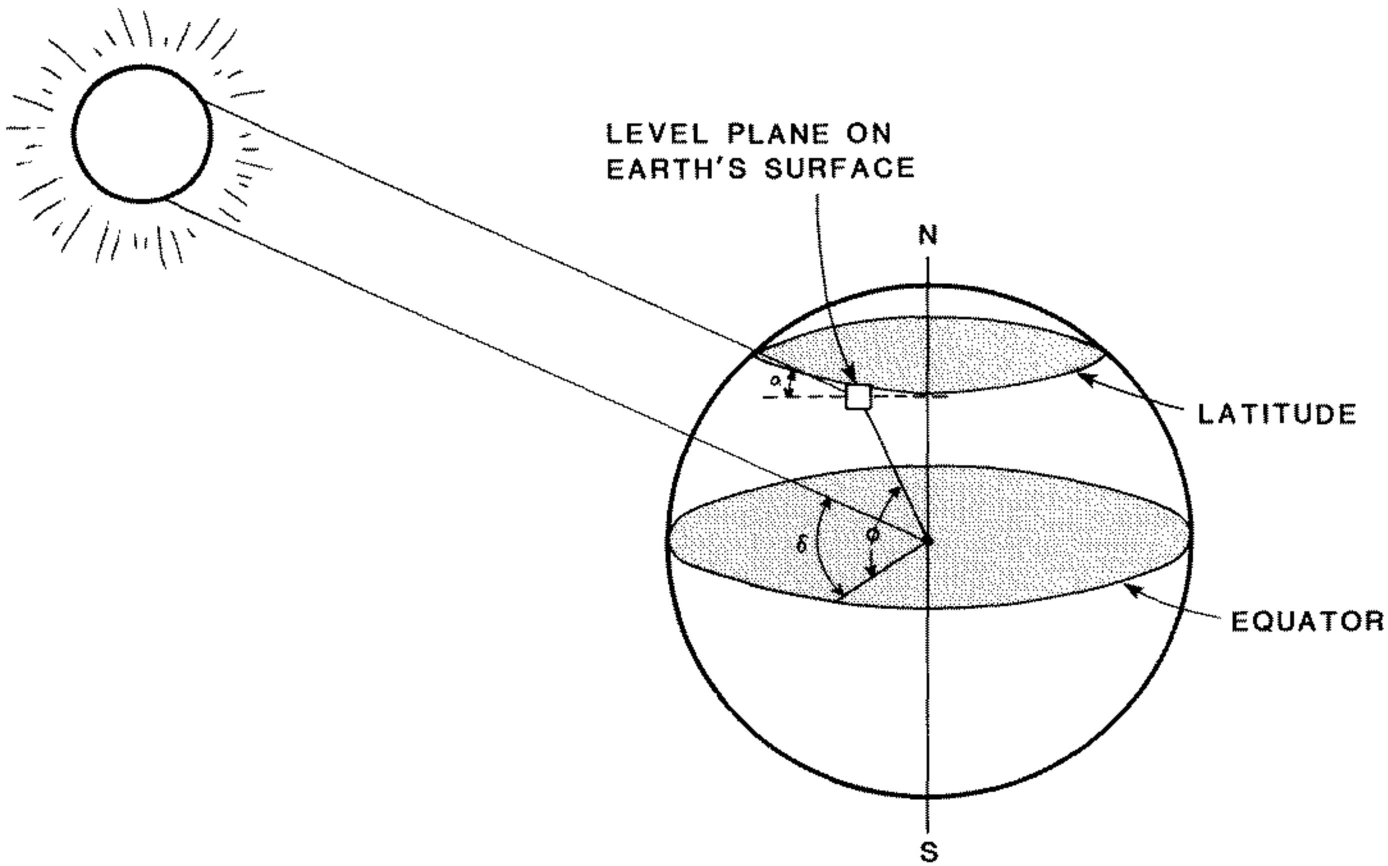


Figure II.1. Solar angle measurements.

Sunrise to Sunset Duration

The sunrise to sunset duration at a specific site is a function of latitude, time of year, and topographic features. It can be computed directly from the sunrise/sunset hour angle h_{si}. The average sunrise to sunset duration over the time period n to N is:

$$S_o = (24/\pi)\ \bar{h}_s \qquad \text{II(7)}$$

where S_o ≡ average sunrise to sunset duration at the specific site over the time period n to N (hours)

$\bar{h}_s$ ≡ average sunrise/sunset hour angle over the time period n to N (radians)

Atmospheric Correction

The extra-terrestrial solar radiation is attenuated on its path through the atmosphere by scattering and absorption when encountering gas molecules, water vapor, and dust particles. Furthermore, radiation is reflected from the ground back into the sky, where it is again scattered and reflected back to the ground.

The attenuation of solar radiation due to the atmosphere can be approximated by Beer's law:

$$H_{sa} = (e^{-\eta z})\ H_{sx} \qquad \text{II(8)}$$

where H_{sx} ≡ average daily extra-terrestrial solar radiation (J/m²/sec)

H_{sa} ≡ average daily solar radiation corrected for atmosphere only (J/m²/sec)

η ≡ absorption coefficient (1/m)

z ≡ path length (m)

While Beer's law is valid only for monochromatic radiation, it is useful to predict the form of, and significant variables for, the atmospheric correction equation. Repeated use of Beer's law and recognition of the importance of the optical air mass (path length), atmospheric moisture content (water vapor), dust particles, and ground reflectivity results in a useful empirical atmospheric correction approximation:

$$e^{-\eta z} = [a'' + (1-a'-d)/2]/[1-R_g(1-a'+d)/2] \qquad \text{II(9)}$$

where $a' \equiv$ mean atmospheric transmission coefficient for dust-free moist air after scattering only (decimal)

$a'' \equiv$ mean distance transmission coefficient for dust-free moist air after scattering and absorbtion (decimal)

$d \equiv$ total depletion coefficient of the direct solar radiation by scattering and absorbtion due to dust (decimal)

$R_g \equiv$ total reflectivity of the ground in the vicinity of the site (decimal)

The two transmission coefficients can be calculated by:

$$a' = \exp\{-[0.465 + 0.134\ w]\ [0.129 + 0.171 \exp(-0.880\ m_p)]\ m_p\} \qquad \text{II(10)}$$

$$a'' = \exp\{-[0.465 + 0.134\ w]\ [0.179 + 0.421 \exp(-0.721\ m_p)]\ m_p\} \qquad \text{II(11)}$$

where $w \equiv$ precipitable water content (cm)

$m_p \equiv$ optical air mass (decimal)

The precipitable water content, w, of the atmosphere can be obtained using the following pair of formulas:

$$(1.0640^{T_d})/(T_d+273.16) = (R_h 1.0640^{T_a})/(T_a+273.16) \qquad \text{II(12)}$$

$$w = 0.85 \exp(0.110 + 0.0614\ T_d) \qquad \text{II(13)}$$

where T_a ≡ average daily air temperature (C)

R_h ≡ relative humidity (decimal)

T_d ≡ mean dew point (C)

w ≡ precipitable water content (cm)

The optical air mass is the measure of both the path length and absorption coefficient of a dust-free dry atmosphere. It is a function of the site elevation and instantaneous solar altitude. The solar altitude varies according to the latitude of the site, time of year, and time of day. For practical application, the optical air mass can be time-averaged over the same time period as the extra-terrestrial solar radiation. The solar altitude function is:

$$\alpha_i = \arcsin \{[\sin\phi \sin\delta_i] + [\cosh (\cos\phi \cos\delta_i)]\} \quad \text{II(14)}$$

$$\bar{\alpha} = \{\sum_{i=n}^{N} [(\int_0^{h_{s,i}} \alpha_i \, dh)/h_{s,i}]\}/[N-n+1] \quad \text{II(15)}$$

where ϕ ≡ site latitude (radians)

δ_i ≡ sun declination on day i (radians)

h ≡ instantaneous hour angle (radians)

$h_{s,i}$ ≡ sunrise/sunset hour angle for day i (radians)

n ≡ first day in time period (Julian day)

N ≡ last day in time period (Julian day)

i ≡ day counter (Julian day)

α_i ≡ instantaneous solar altitude during day i (radians)

$\bar{\alpha}$ ≡ average solar altitude over time period n to N (radians)

Equations II(14) and II(15) can be solved by numerical integration to obtain a precise solution. However, if the time periods do not exceed a month, a reasonable approximation to the solution is:

$$\alpha_i = \arcsin \{[\sin\phi \sin\delta_i] + [\cos\phi \cos\delta_i \cos (h_{s,i}/2)]\} \qquad \text{II(16)}$$

$$\bar{\alpha} \approx [\sum_{i=n}^{N} \alpha_i]/[N-n + 1] \qquad \text{II(17)}$$

where α_i ≡ average solar altitude during day i (radians)

The corresponding optical air mass is:

$$m_p = \{[(288-0.0065Z)/288]^{5.256}\}/$$

$$\{\sin \bar{\alpha} + 0.15[(180/\pi)\ \bar{\alpha} + 3.885]^{-1.253}\} \qquad \text{II(18)}$$

where Z ≡ site elevation above mean sea level (m)

$\bar{\alpha}$ ≡ average solar altitude for time period n to N (radians)

m_p ≡ average optical air mass (dimensionless)

The dust coefficient d and ground reflectivity R_g can be estimated from Tables II.1 and II.2, respectively, or they can be calibrated to published solar radiation data (Cinquemani et al. 1978) after cloud cover corrections have been made.

Table II.1. Dust coefficient d (Tennessee Valley Authority 1972:2.15).

Season	Washington, DC		Madison, Wisconsin		Lincoln, Nebraska	
	m_p=1	m_p=2	m_p=1	m_p=2	m_p=1	m_p=2
Winter	-	0.13	-	0.08	-	0.06
Spring	0.09	0.13	0.06	0.10	0.05	0.08
Summer	0.08	0.10	0.05	0.07	0.03	0.04
Fall	0.06	0.11	0.07	0.08	0.04	0.06

Table II.2. Ground reflectivity R_g (Tennessee Valley Authority 1972:2.15).

Ground condition	R_g
Meadows and fields	0.14
Leaf and needle forest	0.07 - 0.09
Dark, extended mixed forest	0.045
Heath	0.10
Flat ground, grass-covered	0.25 - 0.33
Flat ground, rock	0.12 - 0.15
Sand	0.18
Vegetation, early summer, leaves with high water content	0.19
Vegetation, late summer, leaves with low water content	0.29
Fresh snow	0.83
Old snow	0.42 - 0.70

Seasonal variations appear to occur in both d and R_g. These seasonal variations can be expressed analytically, resulting in reasonable estimates of ground solar radiation.

The dust coefficient (d) of the atmosphere can be seasonally distributed by the following empirical relationship:

$$d = d_1 + \{[d_2 - d_1] \sin [(2\pi/365)(D_i - 213)]\} \qquad \text{II(19)}$$

where d_1 ≡ minimum dust coefficient occurring in late July - early August (decimal)

d_2 ≡ maximum dust coefficient occurring in late January - early February (decimal)

D_i ≡ day of year (Julian day); D_i=1 for January 1 and D_i=365 for December 31

The ground reflectivity R_g can be seasonally distributed by the following empirical relationship:

$$R_g = R_{g_1} + \{[R_{g_2} - R_{g_1}] \sin [(2\pi/365)(D_i - 244)]\} \qquad \text{II(20)}$$

where R_{g_1} ≡ minimum ground reflectivity occurring in mid-September (decimal)

R_{g_2} ≡ maximum ground reflectivity occurring in mid-March (decimal)

D_i ≡ day of year (Julian day); D_i=1 for January 1 and D_i=365 for December 31

The average minimum-maximum value for both the dust coefficient and ground reflectivities can be calibrated to actual recorded solar radiation data. Summaries of recorded solar radiation data are available in Cinquemani et al. (1978).

Cloud Cover Correction

Cloud cover significantly reduces direct solar radiation and somewhat reduces diffused solar radiation. The preferred measure of the effect of cloud cover is the "percent possible sunshine" recorded value (S/S_o), as published by NOAA in their Local Climatological Data (LCD's). It is a direct measurement of solar radiation duration:

$$H_{sg} = [0.22 + 0.78 (S/S_o)^{2/3}] H_{sa} \qquad \text{II(21)}$$

where H_{sg} ≡ daily solar radiation at ground level

H_{sa} ≡ solar radiation corrected for atmosphere only

S ≡ actual sunshine duration on a cloudy day

S_o ≡ sunrise to sunset duration at the specific site

If direct S/S_o values are not available, then S/S_o can be obtained from estimates of cloud cover C_ℓ:

$$S/S_o = 1 - C_\ell^{5/3} \qquad \text{II(22)}$$

where C_ℓ ≡ cloud cover (decimal)

Diurnal Solar Radiation

Obviously, the solar radiation intensity varies throughout the 24-hour daily period. It is zero at night, increases from zero at sunrise to a maximum at noon, and decreases to zero at sunset. This diurnal variation can be approximated by:

$$H_{night} = 0 \qquad \text{II(23)}$$

$$H_{day} = (\pi/\bar{h}_s)\, H_{sg} \qquad \text{II(24)}$$

where H_{night} ≡ average nighttime solar radiation (J/m²/sec)

H_{day} ≡ average daytime solar radiation (J/m²/sec)

H_{sg} ≡ average daily solar radiation at ground level (J/m²/sec)

$\bar{h}_s$ ≡ average sunrise/sunset hour angle over the time period n to N (radians)

Solar Radiation that Penetrates the Water

Solar or shortwave radiation can be reflected from a water surface. The relative amount of solar radiation reflected (R_t) is a function of the average solar angle ($\bar{\alpha}$) and the proportion of direct to diffused shortwave radiation. The percent possible sunshine S/S_o indicates the direct-diffused proportions:

$$R_t = A(S/S_o)\,[\bar{\alpha}(180/\pi)]^{B(S/S_o)}\,;\ 0 \le R_t \le 0.99 \qquad \text{II(25)}$$

where R_t ≡ solar-water reflectivity coefficient (decimal)

$\bar{\alpha}$ ≡ average solar altitude (radians)

$A(S/S_o)$ ≡ coefficient as a function of S/S_o

$B(S/S_o)$ ≡ exponent as a function of S/S_o

S/S_o ≡ percent possible sunshine (decimal)

Both $A(S/S_o)$ and $B(S/S_o)$ are based on values given in Tennessee Valley Authority (1972; Table 2.4). The following average high and low cloud values were selected from this table to fit the regression curves shown in equations II (26) and II (27).

C_ℓ	S/S_o	A	A'	B	B'
0	1	1.18	-	-0.77	-
0.2	0.932	2.20	0	-0.97	0
1	0	0.33	-	-0.45	-

where $A' = dA/dC_\ell$ and $B' = dB/dC_\ell$

The resulting curves are:

$$A(S/S_o) = [a_0 + a_1\ (S/S_o) + a_2\ (S/S_o)^2]/[1 + a_3(S/S_o)] \qquad \text{II(26)}$$

$$B(S/S_o) = [b_0 + b_1\ (S/S_o) + b_2\ (S/S_o)^2]/[1 + b_3\ (S/S_o)] \qquad \text{II(27)}$$

where $a_o = 0.3300$ $b_o = -0.4500$

$a_1 = 1.8343$ $b_1 = -0.1593$

$a_2 = -2.1528$ $b_2 = 0.5986$

$a_3 = -0.9902$ $b_3 = -0.9862$

The amount of solar radiation actually penetrating an unshaded water surface is:

$$H_{sw} = (1-R_t)\ H_{sg} \qquad \text{II(28)}$$

where H_{sw} ≡ daily solar radiation entering water (J/m²/sec)

R_t ≡ solar-water reflectivity (decimal)

H_{sg} ≡ daily solar radiation at ground level (J/m²/sec)

SOLAR SHADE

The solar shade factor is a combination of topographic and riparian vegetation shading. The model is a major modification and extension of Quigley's (1981) work. It distinguishes between topographic and riparian vegetation shading, and does so for each side of the stream. Quigley's work was also modified to include the intensity of the solar radiation throughout the entire day and is completely consistent with the heat flux components used with the water temperature model.

Topographic shade dominates the shading effects because it determines the local time of sunrise and sunset. Riparian vegetation is important for shading between local sunrise and sunset only if it casts a shadow on the water surface.

Topographic shade (see Fig. II.2) is a function of the: (1) time of year; (2) stream reach latitude; (3) general stream reach azimuth; and (4) topographic altitude angle. The riparian vegetation is a function of the topographic shade plus the riparian vegetation parameters of: (1) height of vegetation; (2) crown measurement; (3) vegetation offset; and (4) vegetation density. The model allows for different conditions on opposite sides of the stream.

The time of the year (D_i) and stream reach latitude (ϕ) parameters were explained as a part of the solar radiation section. The remaining shade parameters are necessary only to determine the shading effects.

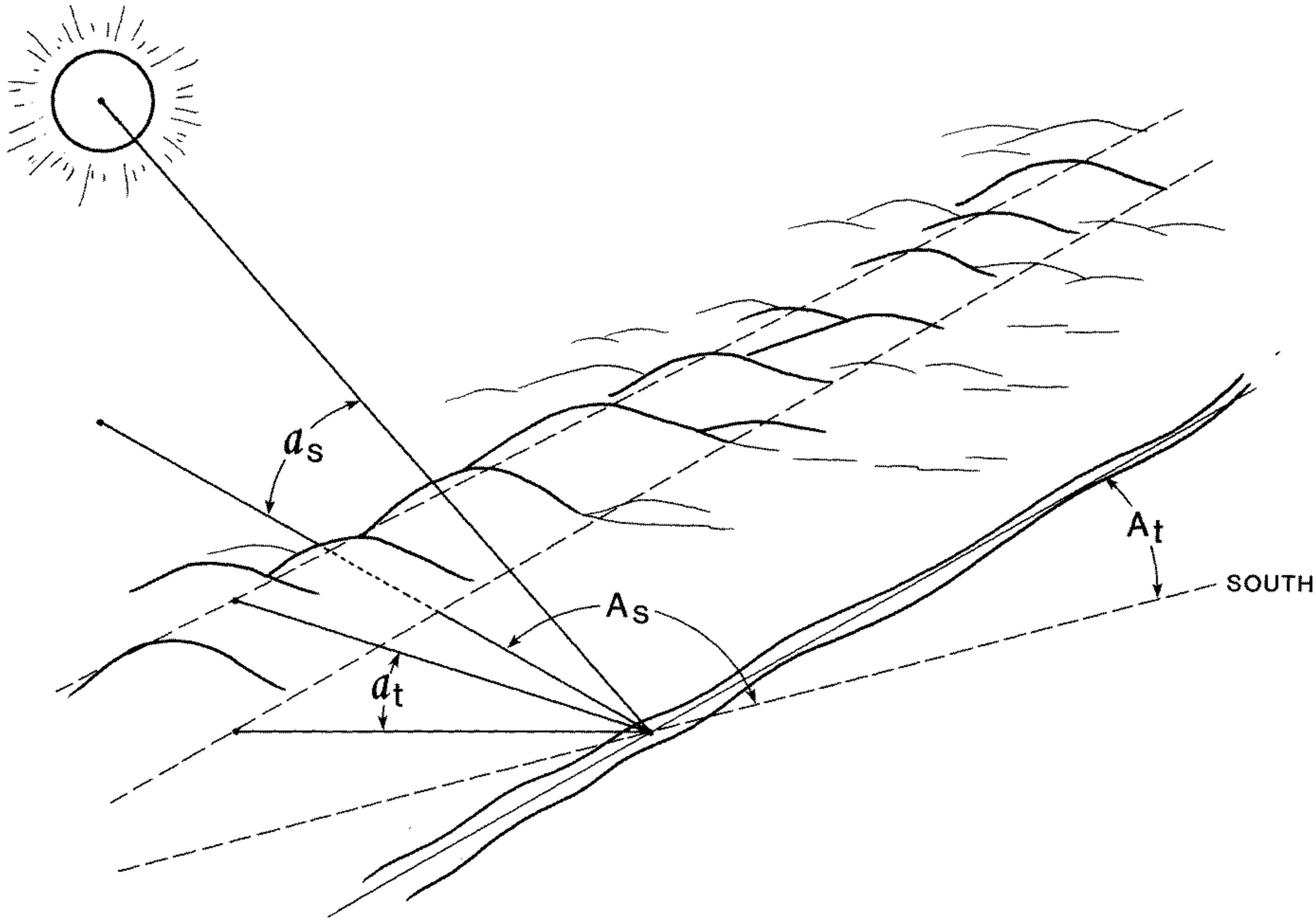


Figure II.2. Local solar and stream orientation angle measurements.

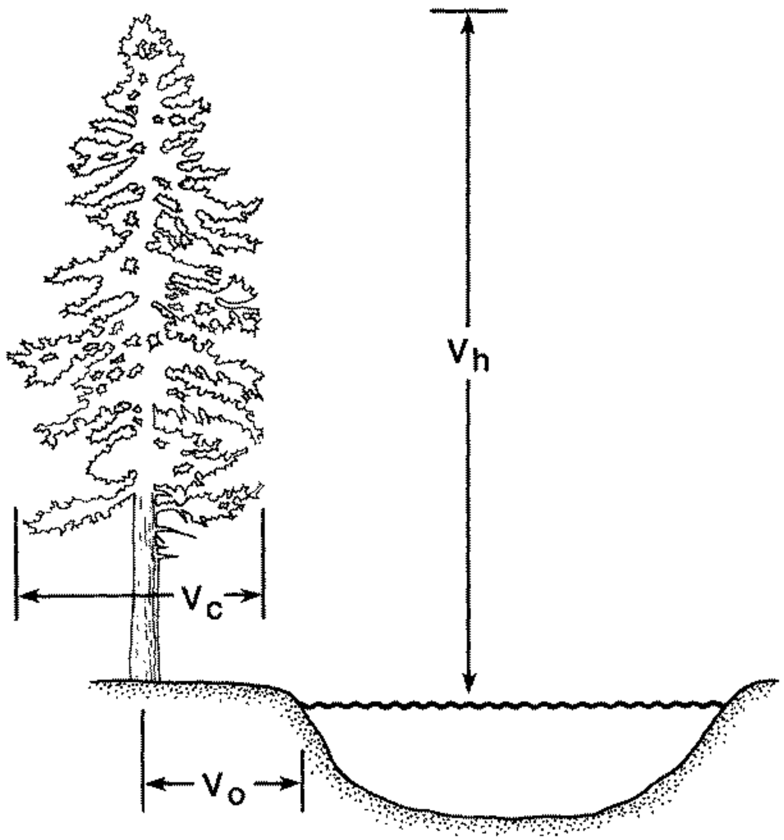
The general stream reach azimuth (A_r) is a measure of the average departure angle of the stream reach from a north-south (N-S) reference line when looking south. For streams oriented N-S, the azimuth is 0°; for streams oriented NW-SE, the azimuth is less than 0°; and, for streams oriented NE-SW, the azimuth is greater than 0°. Therefore, all stream reach azimuth angles are bounded between -90° and +90°. The direction of flow has no affect on determining the azimuth; i.e., two streams with a 180° flow direction difference can have exactly the same azimuth.

The east side of the stream is always on the left-hand side because the azimuth is always measured looking south for streams located in northern latitudes. Note that an E-W oriented stream dictates the east or left-hand side by whether the azimuth is a -90° (left-hand is the north side) or +90° (left-hand is the south side).

The topographic altitude angle (α_t) is the vertical angle from a level line at the streambank to the general top of the local terrian when looking at a 90° angle from the general stream reach azimuth. There are two altitude angles, one for the left-hand side and one for the right-hand side. The altitude is 0 for level plain topography; $\alpha_t > 0$ for hilly or canyon terrain. The altitudes for opposite sides of the stream are not necessarily identical; sometimes streams tend to one side of a valley or they may flow past a bluff line.

The height of vegetation (V_h) is the average maximum existing or proposed height of the overstory riparian vegetation above the water surface. If the height of vegetation changes dramatically (e.g., due to a change in type of vegetation), then subdividing the reach into smaller subreaches may be warranted.

Crown measurement (V_c) is a function of the crown diameter of the vegetation and accounts for overhang. Crown measurement is the average of the maximum diameter of the riparian vegetation immediately adjacent to the stream (Fig. II.3).



Vc ≡ average maximum diameter

Vd ≡ ratio of shortwave radiation eliminated to incoming over entire reach shaded area

Figure II.3. Riparian vegetation shade parameters.

Vegetation offset (V_o) is the average distance of the tree trunks from the water's edge. The net overhang is determined by vegetation offset, together with crown measurement.

Vegetation density (V_d) is a measure of the screening of sunlight that would otherwise pass through the shaded area determined by the riparian vegetation. It accounts for both the continuity of riparian vegetation along the stream bank and the filtering effect of leaves and stands of trees along the stream. For example, if only 50% of the left side of the stream has riparian vegetation (trees) and if those trees actually screen only 50% of the sunlight, then the vegetation density for the left-hand (east side) is 0.25. V_d must always be between 0 and 1.

The solar shade model allows for separate topographic altitudes and riparian vegetation parameters for both the east (left-hand) and west (right-hand) sides of the stream.

The solar shade model is calculated in two steps. First, the topographic shade is determined according to the local sunrise and sunset times for the specified time of year. Then, the riparian shade is calculated between the local sunrise and sunset times.

Topographic shade is defined as the ratio of that portion of solar radiation excluded between level-plain and local sunrise/sunset to the total solar radiation between level-plain sunrise and sunset.

Riparian vegetation shade is defined as the ratio of that portion of the solar radiation over the water surface that is intercepted by the vegetation between local sunrise and sunset to the total solar radiation between level-plain sunrise and sunset.

The following math models are based on the previous rationales. There are five groupings of these models: (1) level-plain sunrise/sunset hour angle and azimuth (h_s and A_{so}); (2) local sunrise/sunset altitude (α_{sr} and α_{ss});

(3) topographic shade (S_t); (4) riparian vegetation shade (S_v); and (5) total solar shade (S_h).

Indicator function notation, I[•], is used. If the relationship shown within the brackets is true, the value of the indicator function is 1; if false, the value is 0. Definitions for each variable are given after the last grouping of math models.

The global conditions of latitude and time of year determine the relative movements of the sun, which affects all subsequent calculations. These conditions were explained in the solar radiation section. The time of year directly determines the solar declination, which is the starting point for the following math models.

Level-Plain Sunrise/Sunset Hour Angle and Azimuth

The level-plain sunrise/sunset group of math models is used to determine the hour angle and corresponding solar azimuth at sunrise and sunset. The solar movements are symmetrical about solar noon; i.e., the absolute values of the sunrise and sunset parameters are identical; they differ only in sign. The math model is:

$$\delta = 0.40928 \cos[(2\pi/365)(172 - D_i)] \quad \text{II(29)}$$

$$h_s = \arccos[-(\sin\phi \sin\delta)/(\cos\phi \cos\delta)] \quad \text{II(30)}$$

$$A_{so} = \arcsin(\cos\delta \sin h_s) \quad \text{II(31)}$$

The level-plain sunrise hour angle is equal to $-h_s$; the sunset hour angle is h_s. The hour angles are referenced to solar noon ($h = 0$). Therefore, the duration from sunrise to solar noon is the same as from solar noon to sunset. One hour of time is equal to 15° of hour angle.

The solar azimuth at sunrise is $-A_{so}$; the sunset azimuth is A_{so}. Azimuths are referenced from the north-south line looking south for streams located in northern latitudes. The absolute values of A_{so} are between 0° and 90° from autumn until spring ($\delta \le 0$) and between 90° and 180° from spring until autumn ($\delta \ge 0$).

Local Sunrise/Sunset Altitudes

Local sunrise and sunset are functions of the local topography, as well as the global conditions. Furthermore, the local terrain may not be identical on both sides of the stream. Also, some streams are oriented such that the sun may rise and set on the same side of the stream during part or even all of the year. The following local sunrise/sunset models properly account for the relative location of the sun with respect to each side of the stream.

The model for the local sunrise is:

$$\alpha_{tr} = \alpha_{te}\ I[-A_{so} \le A_r] + \alpha_{tw}\ I[-A_{so} > A_r] \qquad \text{II(32)}$$

$$h_{sr} = -\arccos\ \{[\sin\alpha_{sr} - (\sin\phi\ \sin\delta)]/[\cos\phi\ \cos\delta]\} \qquad \text{II(33)}$$

$$A_{sr} = -\arccos\ \{[(\sin\phi\ \sin\alpha_{sr}) - (\sin\delta)]/[\cos\phi\ \cos\alpha_{sr}]\} \qquad \text{II(34)}$$

$$\alpha_{sr} = \arctan\ \{(\tan\alpha_{tr})\ [|\sin(A_{sr} - A_r)|]\} \qquad \text{II(35)}$$

but, $\sin\alpha_{sr} \le (\sin\phi\ \sin\delta) + (\cos\phi\ \cos\delta)$.

The model for the local sunset is:

$$\alpha_{ts} = \alpha_{te}\ I[A_{so} \le A_r] + \alpha_{tw}\ I[A_{so} > A_r] \qquad \text{II(36)}$$

$$h_{ss} = \arccos\ \{[\sin\alpha_{ss} - (\sin\phi\ \sin\delta)]/[\cos\phi\ \cos\delta]\} \qquad \text{II(37)}$$

$$A_{ss} = \arccos\ \{[(\sin\phi\ \sin\alpha_{ss}) - (\sin\delta)]/[\cos\phi\ \cos\alpha_{ss}]\} \qquad \text{II(38)}$$

$$\alpha_{ss} = \arctan\ \{(\tan\alpha_{ts})\ [|\sin(A_{ss} - A_r)|]\} \qquad \text{II(39)}$$

but, $\sin\alpha_{ss} \le (\sin\phi\ \sin\delta) + (\cos\phi\ \cos\delta)$.

The reason for the restriction on the $\sin\alpha_{sr}$ and $\sin\alpha_{ss}$ is because the sun never raises higher in the sky than indicated for that latitude and time of year, regardless of the actual topographic altitude. For example, an E-W oriented stream in the middle latitudes could be flowing through a deep canyon that casts continuous shade for a portion of the winter months.

Topographic Shade

Once the level-plain and local sunrise and sunset times are known, the topographic shade can be computed directly in closed form. The definition for topographic shade leads to the following:

$$S_t = \left\{\left[\int_{-h_s}^{h_s} \sin\alpha \, dh\right] - \left[\int_{h_{sr}}^{h_{ss}} \sin\alpha \, dh\right]\right\} \Big/ \left\{\int_{-h_s}^{h_s} \sin\alpha \, dh\right\} \qquad \text{II(40)}$$

which also can be expressed as:

$$S_t = 1 - \left\{\left[\int_{h_{sr}}^{h_{ss}} \sin\alpha \, dh\right] \Big/ \left[\int_{-h_s}^{h_s} \sin\alpha \, dh\right]\right\} \qquad \text{II(41)}$$

and which can be integrated directly to:

$$S_t = 1 - \left\{\left[(h_{ss} - h_{sr})\,(\sin\phi \sin\delta)\right] + \left[(\sin h_{ss} - \sin h_{sr})\,(\cos\phi \cos\delta)\right]\right\} \Big/ \left\{2\left[(h_s \sin\phi \sin\delta) + (\sin h_s \cos\phi \cos\delta)\right]\right\} \qquad \text{II(42)}$$

Riparian Vegetation Shade

The determination of riparian vegetation shade requires keeping track of the shadows cast throughout the sunlight time because only that portion of sunlight over the water surface is of interest. The model must account for the side of the stream where the sun is located and the length of the shadow cast over the water. The model is:

$$V_c = V_{ce}\ I[A_s \le A_r] + V_{cw}\ I[A_s > A_r] \qquad \text{II(43)}$$

$$V_d = V_{de}\ I[A_s \le A_r] + V_{dw}\ I[A_s > A_r] \qquad \text{II(44)}$$

$$V_h = V_{he}\ I[A_s \le A_r] + V_{hw}\ I[A_s > A_r] \qquad \text{II(45)}$$

$$V_o = V_{oe}\ I[A_s \le A_r] + V_{ow}\ I[A_s > A_r] \qquad \text{II(46)}$$

$$\alpha = \arcsin\ [(\sin\phi\ \sin\delta) + (\cos\phi\ \cos\delta\ \cos h)] \qquad \text{II(47)}$$

$$A_s = \{I[h \ge 0\ ] - I[h < 0]\}\ \arccos$$
$$\{[(\sin\phi\ \sin\alpha) - (\sin\delta)]/[\cos\phi\ \cos\alpha]\} \qquad \text{II(48)}$$

$$B_s = \{(V_h\ \cot\alpha)\ [|\sin(A_s - A_r)|]\} + [(V_c/2) - V_o] \qquad \text{II(49)}$$

but, $\quad 0 \le B_s \le \bar{B}$

which, when integrated for the riparian vegetation shade, results in

$$S_v = \left\{ \int_{h_{sr}}^{h_{ss}} (V_d\ B_s\ \sin\alpha)dh \right\} \Bigg/ \left\{ \int_{-h_s}^{h_s} (\bar{B}\ \sin\alpha)dh \right\} \qquad \text{II(50)}$$

It is not possible to integrate equation II(50) completely, so a numerical integration method is required. The suggested numerical approximation is:

$$S_v = \left\{ \left[\sum_{h_{sr}}^{h_{ss}} (V_d\ B_s\ \sin\alpha) \right] \Delta h \right\} \Bigg/ \left\{ 2\bar{B} \left[(h_s\ \sin\phi\ \sin\delta) + (\sin h_s\ \cos\phi\ \cos\delta) \right] \right\} \qquad \text{II(51)}$$

Equations II(43) through II(49) are used to determine the jth value of V_d, B_s, and α for $h_j = h_{sr} + j\Delta h$. Sixteen intervals, or $\Delta h = (h_{ss} - h_{sr})/16$, result in better than 1% precision when using the trapezoidal rule and better than 0.01% precision when using Simpson's rule for functions without discontinuities. However, the function will have a discontinuity if the stream becomes fully shaded due to riparian vegetation between sunrise and sunset. Even so, the numerical error will generally have a negligible effect on water temperatures.

Solar Shade Factor

The solar shade factor is simply the sum of the topographic and riparian vegetation shading:

$$S_h = S_t + S_v \qquad \text{II(52)}$$

Because the solar declination and subsequent solar-related parameters depend on the time of year, it is necessary to calculate the various shade factors for each day of the time period to obtain the average factor for the time periods. This results in shade factors that are completely compatible with the heat flux components. This is done by:

$$S_h = \left[\sum_{i=n}^{N} (S_{t,i} + S_{v,i}) \right] \Big/ \left[N-n + 1 \right] \qquad \text{II(53)}$$

Definitions

The following definitions pertain to all the variables used in this solar shade section:

α ≡ solar altitude (radians)

α_{sr} ≡ local sunrise solar altitude (radians)

α_{ss} ≡ local sunset solar altitude (radians)

α_{te} ≡ eastside topographic altitude (radians)

α_{tr} ≡ sunrise side topographic altitude (radians)

α_{ts} ≡ sunset side topographic altitude (radians)

α_{tw} ≡ westside topographic altitude (radians)

A_r ≡ stream reach azimuth (radians)

A_s ≡ local azimuth at time h (radians)

A_{so} ≡ level-plain sunset azimuth (radians)

A_{sr} ≡ local sunrise solar azimuth (radians)

A_{ss} ≡ local sunset solar azimuth (radians)

B ≡ average stream width (m)

B_s ≡ stream solar shade width (m)

D_i ≡ time of year (Julian day)

S_i ≡ solar declination (radians)

h ≡ solar hour angle (radians)

h_s ≡ level-plain hour sunset hour angle (radians)

h_{sr} ≡ local sunrise hour angle (radians)

h_{ss} ≡ local sunset hour angle (radians)

i ≡ day counter (Julian day)

n ≡ first day in time period (Julian days)

N ≡ last day in time period (Julian days)

ϕ ≡ stream reach latitude (radians)

S_h ≡ total solar shade (decimal)

S_t ≡ topographic shade (decimal)

S_v ≡ riparian vegetation shade (decimal)

V_c ≡ riparian vegetation crown measurement (m)

V_{ce} ≡ eastside crown measurement (m)

V_{cw} ≡ westside crown measurement (m)

V_d ≡ riparian vegetation density factor (decimal)

V_{de} ≡ eastside density (decimal)

V_{dw} ≡ westside density (decimal)

V_h ≡ riparian vegetation height above water surface (m)

V_{he} ≡ eastside height (m)

V_{hw} ≡ westside height (m)

V_o ≡ riparian vegetation waterline offset distance (m)

V_{oc} ≡ eastside offset (m)

V_{ow} ≡ westside offset (m)

METEOROLOGY

There are five meteorological parameters used in the instream water temperature model: (1) air temperature; (2) humidity; (3) sunshine ratio or cloud cover; (4) wind speed; and (5) atmospheric pressure. The first four parameters are input data for a specific elevation in the basin. The meteorology model assumes adiabatic conditions to transpose the air temperature and humidity vertically throughout the basin. Atmospheric pressure is calculated directly from reach elevations. Sunshine ratio or cloud cover and windspeed are assumed constant throughout the basin.

Adiabatic Correction Model

The atmospheric pressure for each reach can be computed with sufficient accuracy directly from the respective reach elevations. The formula is:

$$P = 1013[(288-0.0065Z)/288]^{5.256} \qquad \text{II(54)}$$

where P ≡ atmospheric pressure at elevation Z (mb)

Z ≡ average reach elevation (m)

Moist-air temperatures generally decrease 2°F for every 1,000 ft increase in elevation. Therefore, converting to the metric system, the following formula is used:

$$T_a = T_o + C_T\ (Z-Z_o) \qquad \text{II(55)}$$

where T_a ≡ air temperature at elevation E (C)

T_o ≡ air temperature at elevation E_o (C)

Z ≡ average elevation of reach (m)

$Z_o \equiv$ elevation of station (m)

$C_T \equiv$ moist-air adiabatic temperature correction coefficient = -0.00656 C/m

Both the mean annual air temperature and the actual air temperature for the desired time period must be corrected for elevation.

The relative humidity can also be corrected for elevation, assuming that the total moisture content is the same over the basin and the station. Therefore, the formula is a function of the original relative humidity and the two different air temperatures. It is based on the ideal gas law:

$$R_h = R_o \{[1.0640^{(T_o - T_a)}] [(T_a+273.16)/(T_o+273.16)]\} \qquad \text{II(56)}$$

where $R_h \equiv$ relative humidity for temperature T_a (decimal)

$R_o \equiv$ relative humidity at station (decimal)

$T_a \equiv$ air temperature of reach (C)

$T_o \equiv$ air temperature at station (C)

$0 \leq R_h \leq 1.0$

The sunshine factor is assumed to be the same over the entire basin as over the station. There is no known way to correct the windspeed for transfer to the basin. Certainly local topographic features will influence the windspeed over the water. However, the station windspeed is, at least, an indicator of the basin windspeed. Because the windspeed affects only the convection and evaporation heat flux components and these components have the least reliable coefficients in these models, the windspeed can be used as an important calibration parameter when actual water temperature data are available.

Average Afternoon Meteorological Conditions

The relationships provided in this section are used when diurnal fluctuations are requested.

The average afternoon air temperature is greater than the daily air temperature because the maximum air temperature usually occurs during the middle of the afternoon. This model assumes that:

$$\bar{T}_{ax} = [(5T_{ax}) + (11\bar{T}_a)]/16 \qquad \text{II(57)}$$

where $\bar{T}_{ax}$ ≡ average daytime air temperature between noon/sunset (C)

T_{ax} ≡ maximum air temperature during the 24-hour period (C)

$\bar{T}_a$ ≡ average daily air temperature during the 24-hour period (C)

A regression model was selected to incorporate the significant daily meteorological parameters to estimate the incremental increase of the maximum daytime air temperature above the average daily air temperature. The resulting maximum daytime air temperature model is:

$$T_{ax} = \bar{T}_a + [a_0 + a_1 H_{sx} + a_2 R_h + a_3 (S/S_o)] \qquad \text{II(58)}$$

where T_{ax} ≡ maximum daytime air temperature (C)

$\bar{T}_a$ ≡ daily air temperature (C)

H_{sx} ≡ extra-terrestrial solar radiation (J/m²/sec)

R_h ≡ relative humidity (decimal)

S/S_o ≡ percent possible sunshine (decimal)

a_0 through a_3 ≡ regression coefficients

Some regression coefficients were determined for the "normal" meteorological conditions at 16 selected weather stations. These coefficients and their respective coefficient of multiple correlations R, standard deviation of maximum daytime air temperature $S.T_{ax}$, and probable differences δ are given in Table II.3.

Table II.3. Regression coefficients for maximum daily air temperatures.

Station name	R	(C) S.T_{ax}	(C) δ	Regression coefficients a_0	a_1	a_2	a_3
Phoenix, AZ	.936	0.737	0.194	11.21	-.00581	- 9.55	3.72
Santa Maria, CA	.916	0.813	0.243	18.90	-.00334	-18.85	3.18
Grand Junction, CO	.987	0.965	0.170	3.82	-.00147	- 2.70	5.57
Washington, DC	.763	0.455	0.219	6.64	-.00109	- 7.72	4.85
Miami, FL	.934	0.526	0.140	29.13	-.00626	-24.23	-7.45
Dodge City, KA	.888	0.313	0.107	7.25	-.00115	- 5.24	4.40
Caribou, ME	.903	0.708	0.226	0.87	.00313	0.09	7.86
Columbia, MO	.616	0.486	0.286	4.95	-.00163	- 2.49	4.54
Great Falls, MT	.963	1.220	0.244	9.89	.00274	- 9.56	1.71
Omaha (North), NE	.857	0.487	0.187	9.62	-.00279	- 9.49	6.32
Bismark, ND	.918	1.120	0.332	11.39	-.00052	-13.03	5.97
Charleston, SC	.934	0.637	0.170	9.06	-.00325	- 8.79	7.42
Nashville, TN	.963	0.581	0.117	5.12	-.00418	- 4.55	9.47
Brownsville, TX	.968	0.263	0.049	9.34	-.00443	- 4.28	0.72
Seattle, WA	.985	1.180	0.153	-9.16	.00824	12.79	3.86
Madison, WI	.954	0.650	0.145	1.11	.00219	1.80	3.96
ALL	.867	1.276	0.431	6.64	-.00088	- 5.27	4.86

The corresponding afternoon average relative humidity is:

$$R_{hx} = R_h \, [1.0640^{(\overline{T}_a - \overline{T}_{ax})}] \, [(\overline{T}_{ax}+273.16)/(\overline{T}_a+273.16)] \qquad \text{II(59)}$$

where R_{hx} ≡ average afternoon relative humidity (decimal)

R_h ≡ average daily relative humidity (decimal)

$\overline{T}_a$ ≡ daily air temperature (C)

$\overline{T}_{ax}$ ≡ average afternoon air temperature (C)

HEAT FLUX

There are five basic thermal processes recognized by the heat flux relationships: (1) radiation; (2) evaporation; (3) convection; (4) conduction; and (5) the conversion of energy from other forms to heat (see Fig. II.4).

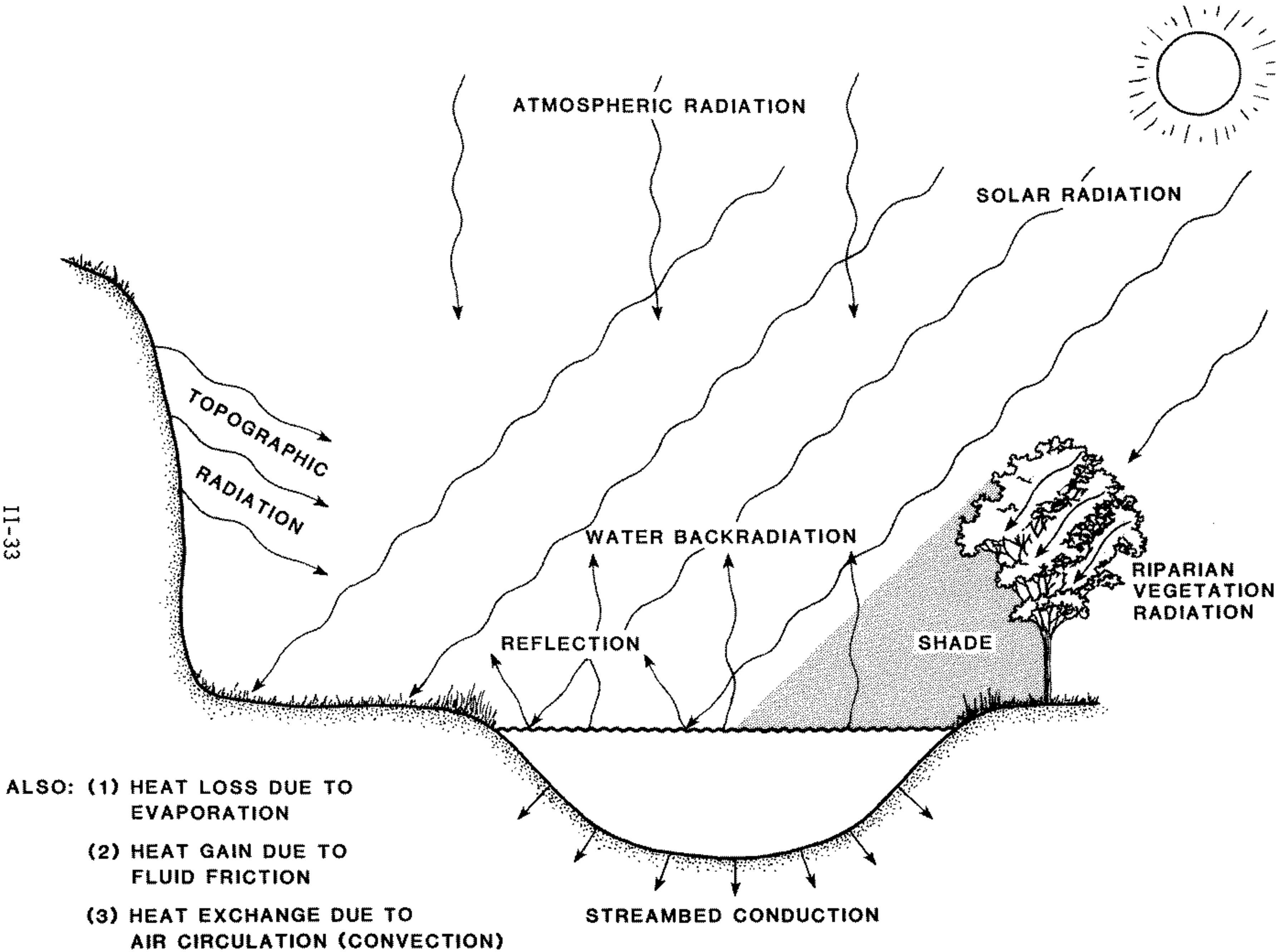


Figure II.4. Heat flux sources.

Thermal Sources

Each heat flux source is considered mutually exclusive and, when added together, accounts for the heat budget of a single column of water. A heat budget analysis would be applicable for a stationary tank of continuously mixed water. However, the transport model is necessary to account for the spatial location of the column of water at any point in time.

Radiation

Radiation is an electromagnetic mechanism, which allows energy to be transported at the speed of light through regions of space that are devoid of matter. The physical phenomena causing radiation is sufficiently well-understood to provide very dependable source-component models. Radiation models have been theoretically derived from both thermodynamics and quantum physics and have been experimentally verified with a high degree of precision and reliability. Radiation is the most dependable component of the heat flux submodel and, fortunately, is also the most important source of heat exchange. Solar, back radiation from the water, atmospheric, riparian vegetation, and topographic features are the major sources of radiation heat flux. There is interaction between these various sources; e.g., riparian vegetation screens both solar and atmospheric radiation while replacing it with its own radiation.

Solar Radiation Corrected for Shading

The solar radiation penetrating the water must be further modified by local shading due to riparian vegetation and other sources. The resulting model is:

$$H_s = (1-S_h)\, H_{sw} \qquad \text{II(60)}$$

where S_h ≡ solar shade factor (decimal)

H_{sw} ≡ average daily solar radiation entering unshaded water (J/m²/sec)

H_s ≡ average daily solar radiation entering shaded water (J/m²/sec)

Atmospheric Radiation

The atmosphere emits longwave radiation (heat). There are five factors affecting the amount of longwave radiation entering the water: (1) the air temperature is the primary factor; (2) the atmospheric vapor pressure affects the emissivity; (3) the cloud cover converts the shortwave solar radiation into additional longwave radiation, which are sort of "hot spots" in the atmosphere; (4) the reflection of longwave radiation at the water-air interface; and (5) the interception of longwave radiation by vegetative canopy cover or shading. An equation that approximates longwave atmospheric radiation entering the water is:

$$H_a = (1-r_\ell)(1-S_a)(1+kC_\ell^2)\ [\varepsilon_a \sigma (T_a+273.16)^4] \qquad \text{II(61)}$$

where $C_\ell = [1-(S/S_o)]^{3/5} \equiv$ cloud cover (decimal)

$S/S_o \equiv$ sunshine ratio (decimal)

$k \equiv$ type of cloud cover factor $(0.04 \leq k \leq 0.24)$

$\varepsilon_a \equiv$ atmospheric emissivity (decimal)

$S_a \equiv$ atmospheric shade factor (decimal)

$r_\ell \equiv$ longwave radiation reflection (decimal)

$T_a \equiv$ air temperature (C)

$\sigma = 5.672 \cdot 10^{-8}$ $(J/m^2/sec/K^4) \equiv$ Stefen-Boltzman constant

The preferred estimate of ε_a is:

$$\varepsilon_a = a+b\sqrt{e_a} \text{ (decimal)} \qquad \text{II(62)}$$

$a = 0.61$

$b = 0.05$

$$e_a \equiv \text{vapor pressure} = R_h\ [6.60(1.0640)^{T_a}] \text{ (mb)} \qquad \text{II(63)}$$

An alternate estimate of ε_a is:

$$\varepsilon_a = 9.062 \cdot 10^{-6} (T_a + 273.16)^2 \text{ (decimal)} \qquad \text{II(64)}$$

The preferred estimate accounts for water vapor, which also absorbs solar radiation (shortwave), which, in turn, is converted into longwave radiation. If the absorbtion of solar radiation is overpredicted, then some of the overprediction is returned as longwave and vice versa. Therefore, errors in shortwave radiation tend to be compensated for by errors in longwave radiation. The alternate form for ε_a is mentioned in the literature as a simpler model and possibly a better predictor of longwave radiation alone. However, for the purpose of predicting water temperatures, the form of radiation (shortwave or longwave) ultimately makes little difference, as long as the total heat exchange is accurately predicted. The alternate form is only used when a desired solution technique requires simple steps.

Assuming k = 0.17, r_ℓ = 0.03, and using the preferred estimate of ε_a, this equation reduces to:

$$H_a = (1-S_a)(1+0.17C_\ell^2)[3.36+0.706(R_h \cdot 1.0640^{T_a})^{1/2}][10^{-8}(T_a+273.16)^4] \qquad \text{II(65)}$$

The atmospheric shade factor (S_a) is assumed to be identical to the solar shade factor (S_h).

Topographic Features Radiation

Currently, the radiation from topographic features is assumed to be included as a part of the riparian vegetation radiation. Therefore, no separate component model is used.

Riparian Vegetation Radiation

The riparian vegetation intercepts all other forms of radiation and radiates its own form. Essentially, it totally eliminates the estimated shade amount of solar radiation, but replaces the other longwave sources with its own longwave source. The difference is mostly in the emissivity between the different longwave sources. The model is:

$$H_v = (\varepsilon_v \sigma)\ S_v\ (T_a + 273.16)^4 \qquad \text{II(66)}$$

where ε_v ≡ vegetation emissivity = 0.9526 (decimal)

σ ≡ Stefan-Boltzman constant = $5.672 \cdot 10^{-8}$ J/m²/sec/K⁴

H_v ≡ riparian vegetation radiation (J/m²sec)

S_v ≡ riparian vegetation shade factor (decimal)

T_a ≡ riparian vegetation temperature, assumed to be the ambient air temperature (C)

The riparian vegetation shade factor (S_v) is assumed to be identical to the solar shade factor (S_h).

Water Radiation

The water emits radiation, and this is the major balancing heat flux that prevents the water temperature from increasing without bounds. The model is:

$$H_w = \varepsilon_w \sigma (T_w + 273.16)^4 \qquad \text{II(67)}$$

where H_w ≡ water radiation (J/m²/sec)

T_w ≡ water temperature (C)

ε_w ≡ water emissivity = 0.9526 (decimal)

σ ≡ Stefan-Boltzman constant = $5.672 \cdot 10^{-8}$ J/m²/sec/K⁴

A first-order approximation to equation II(67) with less than ± 1.8% error of predicted radiation for $0\ C \leq T_w \leq 40\ C$ is:

$$\hat{H}_w = 300 + 5.500\ T_w \qquad \text{II(68)}$$

where $\hat{H}_w \equiv$ approximate water radiation (J/m²/sec)

$T_w \equiv$ water temperature (C)

Stream Evaporation

Evaporation, and its counterpart condensation, require an exchange of heat. The isothermal (same temperature) conversion of liquid water to vapor requires a known fixed amount of heat energy called the heat of vaporization. Conversely, condensation releases the same amount of heat. The rate of evaporation (the amount of liquid water converted to vapor) is a function of both the circulation and vapor pressure (relative humidity) of the surrounding air. If the surrounding air is at 100% relative humidity, no net evaporation occurs. If there is no circulation of air, then the air immediately above the water surface quickly becomes saturated and no further net evaporation occurs.

Evaporation, while second in importance to radiation, is a significant form of heat exchange. Most available models are derived from lake environments and are probably the least reliable of the thermal processes modeled. However, one model was derived from a single set of open channel flow data. Both model types are included below. They differ only in the wind function used. The wind function for the flow-type model was adjusted by approximately 75% to better match recorded field data.

The first model was obtained largely from lake data and is used only for small, hand-held calculator solution techniques. The second model is the preferred one. It was obtained from open channel flow data and is used for all but the simplest solution technique.

The lake-type model is:

$$H_e = (26.0W_a)[R_h(1.0640)^{T_a} - (1.0640)^{T_w}] \qquad \text{II(69)}$$

The flow-type model is:

$$H_e = (40.0 + 15.0W_a)[R_h(1.0640)^{T_a} - (1.0640)^{T_w}] \qquad \text{II(70)}$$

where $H_e \equiv$ evaporation heat flux (J/m²/sec)

$W_a \equiv$ wind speed (m/sec)

$R_h \equiv$ relative humidity (decimal)

$T_a \equiv$ air temperature (C)

$T_w \equiv$ water temperature (C)

Convection

Convection can be an important source of heat exchange at the air-water interface. Air is a poor conductor, but the ability of the surrounding air to circulate, either under forced conditions from winds or freely due to temperature differences, constantly exchanges the air at the air-water interface. Convection affects the rate of evaporation and, therefore, the two models are related. But the actual heat exchange due to the two different sources are mutually exclusive. Convection is not quite as important as evaporation as a source of heat flux but is still significant. The available convection models suffer from the same defects because they both use the same circulation model.

The current convection models are largely based on lake data but are used here. The convection model is based on the evaporation model, using the Bowen ratio:

$$\text{Bowen ratio} = B_f\ P(T_w - T_a)/(e_s - e_a) \qquad \text{II(71)}$$

where $P \equiv$ atmospheric pressure (mb)

$T_w \equiv$ water temperature (C)

$T_a \equiv$ air temperature (C)

$e_s \equiv$ saturation vapor pressure (mb)

$e_a \equiv$ air vapor pressure (mb)

$B_f \equiv$ Bowen ratio factor

Air convection heat exchange is approximated by the product of the Bowen ratio and the evaporation heat exchange:

$$H_c = RH_e \qquad \text{II(72)}$$

where H_c ≡ air convection heat flux (J/m²/sec)

R ≡ Bowen ratio (decimal)

H_e ≡ evaporation heat flux (J/m²/sec)

Because the air convection heat flux is a function of the evaporation heat flux, two models are offered. The first, the simplest, is a lake-type model. The second, the preferred, is a flow-type model.

The lake-type model is:

$$H_c = (2.55 \cdot 10^{-3} W_a)\, P(T_w - T_a) \qquad \text{II(73)}$$

The flow-type model is:

$$H_c = (3.75 \cdot 10^{-3} + 1.40 \cdot 10^{-3} W_a)\, P(T_w - T_a) \qquad \text{II(74)}$$

where H_c ≡ air convection heat flux (J/m²/sec)

W_a ≡ wind speed (m/sec)

P ≡ atmospheric pressure (mb)

T_w ≡ water temperature (C)

T_a ≡ air temperature (C)

Streambed Conduction

Conduction occurs when a temperature gradient (temperature difference between two points) exists in a material medium in which there is molecular contact. The only important conduction heat flux component is through the streambed. The thermal processes are reasonably well understood, although some of the necessary data may not be easily obtained without certain assumptions.

However, the importance of this component, while not negligible, does allow for some liberties, and suitable predictions can be made for most applications.

Streambed conduction is a function of the difference in temperature between the streambed at the water-streambed interface and the streambed at an equilibrium ground temperature at some depth below the streambed elevation, the equilibrium depth, and the thermal conductivity of the streambed material. The equation is:

$$H_d = K_g[(T_g - T_w)/\Delta Z_g] \qquad \text{II(75)}$$

where H_d = conduction heat flux (J/m²/sec)

K_g ≡ thermal conductivity of the streambed material (J/m/sec/C)

T_g ≡ streambed equilibrium temperature (C)

T_w ≡ streambed temperature at the water-streambed interface, assumed to be the water temperature (C)

ΔZ_g ≡ equilibrium depth from the water-streambed interface (m)

K_g = 1.65 J/m/sec/C for water-saturated sands and gravel mixtures (Pluhowski 1970)

The two terms, $K_g/\Delta Z_g$, when combined, are called the streambed thermal gradient.

Stream Friction

Heat is generated by fluid friction as the water flows downstream, either as work done on the boundaries or as internal fluid shear. That portion of the potential energy (elevation) of the flowing water that is not converted to other uses (e.g., hydroelectric generation) is converted to heat. When ambient conditions are below freezing and the water in a stream is still flowing, part of the reason may be due to this generation of heat due to friction. The available model is straightforward, simple to use, and solidly justified by basic physics. Fluid friction is the least significant source of heat flux, but it can be noticeable for steep mountain streams during cooler conditions.

The stream friction model is:

$$H_f = 9805\ (Q/\bar{B})S_f \qquad \text{II(76)}$$

where $H_f \equiv$ fluid friction heat flux (J/m²/sec)

$S_f \equiv$ rate of heat energy conversion, generally the stream gradient (m/m)

$Q \equiv$ discharge (cms)

$\bar{B} \equiv$ average top width (m)

Net Heat Flux

The various heat flux components, when added together, form the net heat flux equation:

$$H_n = H_a + H_c + H_d + H_e + H_s + H_v - H_w \qquad \text{II(77)}$$

where $H_n \equiv$ net heat flux

When the equations for the separate components are substituted into equation II(77), it can be reduced to:

$$H_n = A(T_w+273.16)^4 + BT_w + C\ (1.0640)^{T_w} - D \qquad \text{II(78)}$$

where $A = 5.40 \cdot 10^{-8}$

$B = (C_r \cdot C_e\ P) + (K_g/\Delta Zg)$

$C = (40.0 + 15.0W_a)$

$D = H_a + H_f + H_s + H_v + (C_r \cdot C_e\ PT_a) +$

$[T_g(K_g/\Delta Z_g)] + [C_e\ R_h\ (1.0640^{T_a})]$

$C_e = a + bW_a + c\sqrt{W_a}$

$C_r = B_f/6.60$

The equilibrium water temperature T_e is defined as the water temperature when the net heat flux is zero for a constant set of input parameters:

$$A(T_e+273.16)^4 + BT_e + C\,(1.0640)^{T_e} - D = 0 \qquad \text{II(79)}$$

The solution of equation II(79) for T_e, given A, B, C, and D, is the equilibrium water temperature of the stream for a fixed set of meteorologic, hydrologic, and stream geometry conditions. A physical analogy is that, as a constant discharge of water flows downstream in a prismatic stream reach under a constant set of meteorologic conditions, the water temperature will asymptotically approach the equilibrium water temperature regardless of the initial water temperature.

The first order thermal exchange coefficient K_1 is the first derivative of equation II(78) (dH/dT_w) taken at T_e:

$$K_1 = 4A(T_e+273.16)^3 + B + [C\ln\,(1.0640)]\,(1.0640)^{T_e} \qquad \text{II(80)}$$

The second order thermal exchange coefficient is the coefficient for a second order term that collocates the actual heat flux at the initial water temperature (T_o) with a first-order Taylor series expansion about T_e:

$$K_2 = \{[A(T_o+273.16)^4 + BT_o + C(1.0640)^{T_o} - D]-[K_1(T_o-T_e)]\}/[(T_o-T_e)^2] \qquad \text{II(81)}$$

Therefore, a first-order approximation of equation II(78), with respect to the equilibrium temperature, is:

$$H_n = K_1\,(T_e - T_w) \qquad \text{II(82)}$$

A second order approximation of equation II(78), with respect to the equilibrium temperature, is:

$$H_n = K_1\,(T_e - T_w) + K_2\,(T_e - T_w)^2 \qquad \text{II(83)}$$

HEAT TRANSPORT

The heat transport model is based on the dynamic temperature - steady flow equation. This equation, when expressed as an ordinary differential equation, is identical in form to the less general steady-state equation. However, it requires different input data and requires tracking the mass movement of water downstream. The simultaneous use of the two identical equations with different sets of input data is acceptable because the actual water temperature equals the average daily water temperature twice each day, once at night and once during the day.

The steady-state equation assumes that the input parameters are constant for each 24-hour period. Therefore, the solar radiation, meteorological, and hydrology parameters are 24-hour averages. It follows, then, that the predicted water temperatures are also 24-hour averages. Hence, the term "average daily" means 24-hour averages, from midnight to midnight, for each parameter.

The dynamic model allows the 24-hour period to be divided into night and day times. Although the solar radiation and meteorological parameters for nighttime and daytime are different, they are considered constant. Because the dynamic model is a steady flow model, the discharges are constant over the 24-hour period.

The water temperature is at a minimum at sunrise and continually rises during the day, with the average daily water temperature occurring near noon. At sunset, the water temperature is at its maximum, then it begins to cool, with the average daily temperature again occurring near midnight. Just before sunrise, the temperature returns to the minimum.

The steady-state equation, with input based on 24-hour averages, can be used to predict the average daily water temperatures throughout the entire stream network. Because these average daily values actually occur near midnight and midday, the dynamic model can be used to track the column of water between midnight and sunrise and between midday and sunset to determine the minimum nighttime and maximum daytime water temperatures, respectively. Of course, the proper solar radiation and meteorological parameters reflecting night and daytime conditions must be used for the dynamic model.

A minimum/maximum simulation model requires that the upstream average daily water temperature stations at midnight/midday for the respective sunrise/sunset stations be simulated. This step is a simple hydraulic procedure, requiring only a means to estimate the average flow depth.

Dynamic Temperature - Steady Flow

A control volume for the dynamic temperature - steady flow equation is shown in Figure II.5. It allows for lateral flow. To satisfy the fundamental laws of physics regarding conservation of mass and energy, the heat energy in the incoming waters less the heat energy in the outgoing water plus the net heat flux across the control volume boundaries must equal the change in heat energy of the water within the control volume. The mathematical expression is:

$$\{[\rho c_p(QT)_i - \rho c_p(QT)_o] + [\rho c_p q_\ell T_\ell \Delta x] + [(B\Sigma H)\ \Delta x]\}\Delta t$$
$$= \{[\rho c_p(\partial(AT)/\partial t)]\Delta t\}\Delta x \qquad \text{II(84)}$$

where
ρ ≡ water density (M/L^3)
c_p ≡ specific heat of water ($E/M/T$)
Q ≡ discharge (L^3/t)
T ≡ water temperature (T)
q_ℓ ≡ lateral flow (L^2/t)
T_ℓ ≡ lateral flow temperature (T)
x ≡ distance (L)
t ≡ time (t)
A ≡ flow area (L^2)
i ≡ inflow index

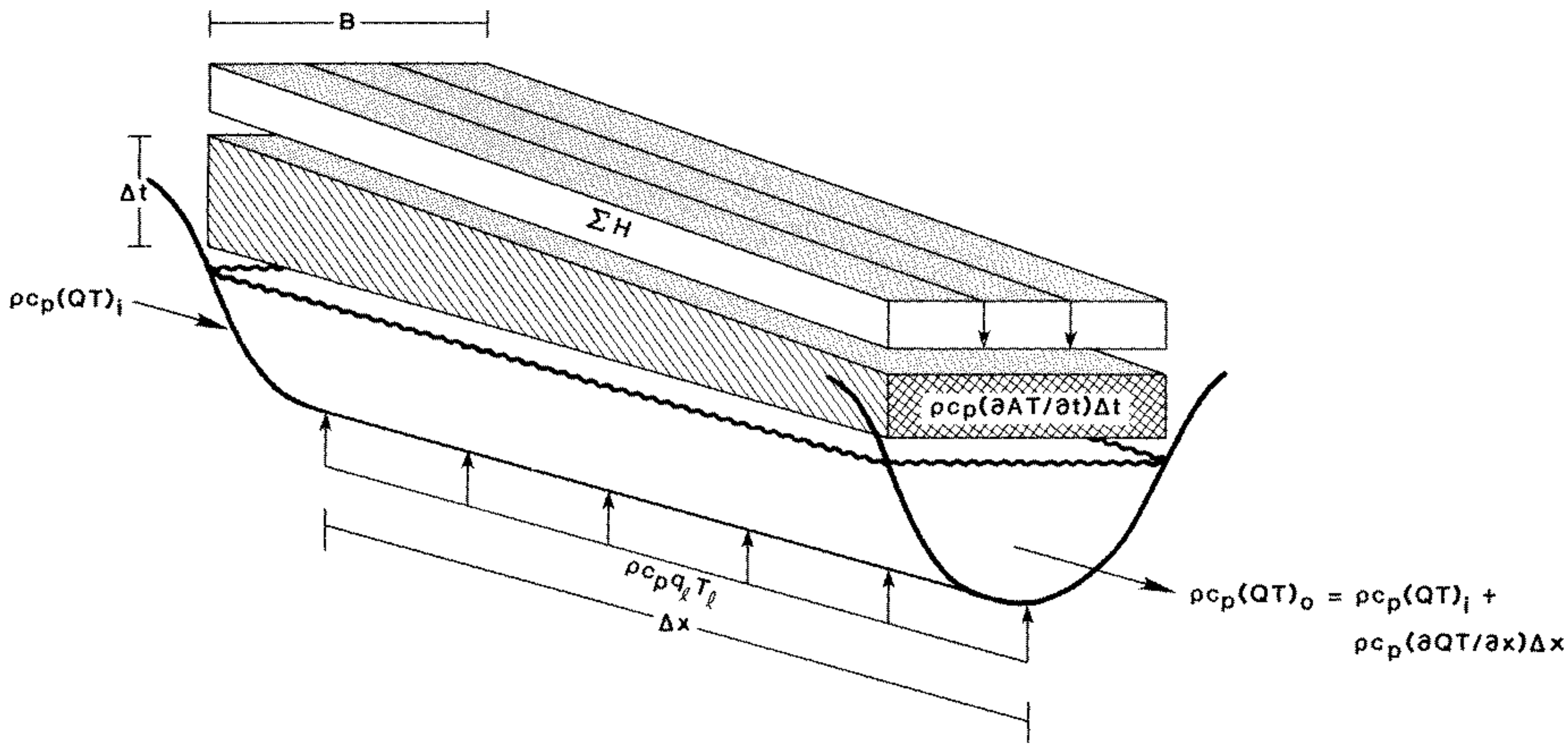


Figure II.5. Dynamic energy control volume.

o ≡ outflow index

B ≡ stream top width (L)

ΣH = net heat flux across control volume ($E/L^2/t$)

note: units are

M - mass

T - temperature

L - length

t - time

E - heat energy

Equation II(84) reduces to:

$$\partial(AT)/\partial t + \partial(QT)/\partial x = q_\ell T_\ell + (\bar{B}\Sigma H)/(\rho c_p) \qquad \text{II(85)}$$

Assuming steady flow ($\partial A/\partial t=0$), letting $H_n = \Sigma H$, recognizing $q_\ell \equiv \partial Q/\partial x$, and dividing through by Q, leads to:

$$(A/Q)\ (\partial T/\partial t) + \partial T/\partial x = [(q_\ell/Q)\ (T_\ell - T)] + [(\bar{B}H_n)/(Q\rho c_p)] \qquad \text{II(86)}$$

|<— dynamic term —>|<— steady-state equation —>|

|<— dynamic temperature - steady flow equation —>|

If the dynamic temperature term is neglected ($\partial T/\partial t = 0$), then the steady-state equation is left. Because the steady-state equation contains only a single independent variable x, it converts directly into an ordinary differential equation with no mathematical restrictions:

$$dT/dx = [(q_\ell/Q)\ (T_\ell - T)] + [(\bar{B}H_n)/(Q\rho c_p)] \qquad \text{II(87)}$$

If the dynamic temperature term is not neglected ($\partial T/\partial t \neq 0$), then equation II(86) can still be solved using the classical mathematical technique known as the "Method of Characteristics." If, for notional purposes only, we substitute:

$$\Phi \equiv [(q_\ell/Q)\ (T_\ell - T)] + [(\bar{B}H_n)/(Q\rho c_p)] \qquad \text{II(88)}$$

into equation II(86) and use the definition of the total derivative for the dependent variable T, a resulting pair of dependent simultaneous first-order partial differential equations emerge:

$$(A/Q)\ (\partial T/\partial t) + (1)\ (\partial T/\partial x) = \Phi \qquad \text{II(89)}$$

$$(dt)\ (\partial T/\partial t) + (dx)\ (\partial T/\partial x) = dT \qquad \text{II(90)}$$

Because the equations are dependent, the solution of the coefficient matrix is zero:

$$\begin{bmatrix} (A/Q) & 1 \\ dt & dx \end{bmatrix} = 0$$

which leads to the characteristic line equation:

$$dx = (Q/A)dt \qquad \text{II(91)}$$

For the same reason, the solution matrix is also zero:

$$\begin{bmatrix} \Phi & 1 \\ dt & dx \end{bmatrix} = 0$$

which leads to the characteristic integral equation:

$$dT/dx = [(q_\ell/Q)\ (T_\ell - T)] + [(\bar{B}H_n)/(Q\rho c_p)] \qquad \text{II(92)}$$

when Φ is replaced by its original terms of equation II(88).

Equation II(92) is identical in form to equation II(87) and is valid for dynamic temperature conditions when solved along the characteristic line equation [equation II(91)]. This presents no special problem because equation II(91) simply tracks a column of water downstream, an easily simulated task.

Closed-form solutions for the ordinary differential equation forms [equations II(91) and II(92)] of the dynamic temperature-steady flow equations are possible with two important assumptions: (1) uniform flow exists; and (2) first and/or second order approximations of the heat flux versus water temperature relationships are valid.

First-Order Solutions

First-order solutions are possible for all three cases of q_ℓ: Case 1, $q_\ell > 0$; Case 2, $q_\ell < 0$; and Case 3, $q_\ell = 0$. The ordinary differential equation with the first-order substitution is:

$$dT/dx = [(q_\ell/Q)\ (T_\ell - T)] + [K_1\ (T_e - T)\bar{B}/(\rho c_p Q)] \qquad \text{II(93)}$$

Case 1, $q_\ell > 0$:

Because $Q = Q_o + q_\ell\ x$, equation II(93) becomes:

$$[Q_o + q_\ell x]\ dT/dx = \{[q_\ell T_\ell] + [(K_1\bar{B})/(\rho c_p)]T_e\} - \{q_\ell + [(K_1\bar{B})/(\rho c_p)]\}T \qquad \text{II(94)}$$

If we let: $a = [q_\ell T_\ell] + [(K_1\bar{B})/(\rho c_p)]T_e$

$b = q_\ell + [(K_1\bar{B})/(\rho c_p)]$

Then equation II(94) becomes:

$$(Q_o + q_\ell x)\ dT/dx = a - bT \qquad \text{II(95)}$$

Using separation of variables,

$$\int_{T_o}^{T_w} \frac{dT}{a-bT} = \int_{0}^{x_o} \frac{dx}{Q_o + q_\ell x} \qquad \text{II(96)}$$

the solution is:

$$T_w = (a/b) - [(a/b) - T_o]\,[1 + (q_\ell x_o/Q_o)]^{(-b/q_\ell)} \qquad \text{II(97)}$$

Case 2, $q_\ell < 0$:

If $q_\ell < 0$, then $T_\ell = T$ and equation II(93) becomes:

$$[Q_o + q_\ell x_o]\; dT/dx = [(K_1\bar{B})/(\rho c_p)]\;[T_e - T] \qquad \text{II(98)}$$

The solution is:

$$T_w = T_e - [T_e - T_o]\,[1 + (q_\ell x_o/Q_o)]^{[(q_\ell - b)/q_\ell]} \qquad \text{II(99)}$$

Case 3, $q_\ell = 0$:

If $q_\ell = 0$, then $Q \neq Q(x)$ and equation II(93) becomes:

$$dT/dx = [(K_1\bar{B})/(\rho c_p Q)]\;[T_e - T] \qquad \text{II(100)}$$

The solution is:

$$T_w = T_e - [T_e - T_o]\,\exp\,[-(K_1\bar{B}x_o)/(\rho c_p Q)] \qquad \text{II(101)}$$

Second-Order Solutions

A second-order solution for case 3 is as follows:

Letting $q_\ell = 0$ and using equation II(83) results in:

$$dT/dx = [K_1(T_e - T) + K_2\,(T_e - T)^2]\bar{B}/(\rho c_p Q_o) \qquad \text{II(102)}$$

The solution is:

$$T_w = T_e - \frac{(T_e - T_o)\ \exp\left[-(K_1\bar{B}x_o)/(\rho c_p Q_o)\right]}{1 + (K_2/K_1)\ (T_e - T_o)\ \{1-\exp\left[-(K_1\bar{B}x_o)/(\rho c_p Q_o)\right]\}} \qquad \text{II(103)}$$

Using the first-order solution and making second-order corrections according to the form suggested by equation II(103) results in:

$$T_w = T_e' - [(T_e' - T_o)\ R]/[1 + (K_2/K_1)\ (T_e' - T_o)\ (1-R)] \qquad \text{II(104)}$$

where

$$a = [q_\ell T_\ell] + [(K_1\bar{B})/(\rho c_p)]T_e \qquad \text{II(105)}$$

$$b = q_\ell + (K_1\bar{B})/(\rho c_p) \qquad \text{II(106)}$$

Case 1, $q_\ell > 0$:

$$T_e' = a/b \qquad \text{II(107)}$$

$$R = [1 + (q_\ell x_o/Q_o)]^{(-b/q_\ell)} \qquad \text{II(108)}$$

Case 2, $q_\ell < 0$:

$$T_e' = T_e \qquad \text{II(109)}$$

$$R = [1 + (q_\ell x_o/Q_o)]^{[(q_\ell - b)/q_\ell]} \qquad \text{II(110)}$$

Case 3, $q_\ell = 0$:

$$T_e' = T_e \qquad \text{II(111)}$$

$$R = \exp\left[-(bx_o)/Q_o\right] \qquad \text{II(112)}$$

Figure II.6 shows a typical longitudinal water temperature profile.

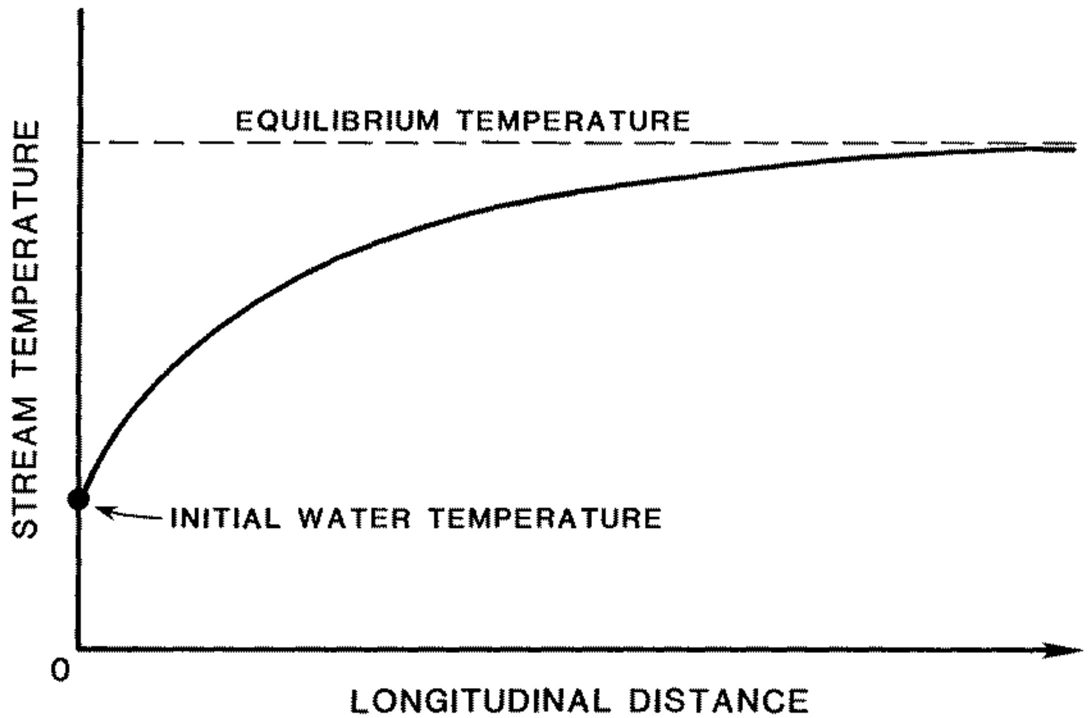


Figure II.6. Typical longitudinal water temperature profile predicted by the heat transport equation.

Time Periods

The basic math model for the overall basin network is a steady-state model because it assumes that the input is a constant over an indefinite period of time. Conceptually, it assumes that the input conditions exist sufficiently long for the steady-state results to reach the lowest point in the network. If the travel time from the upstream-most point to the downstream end of the network becomes significant compared to the time period, the results become less reliable.

If the travel time to the lowest point is 30 days, it should be recognized that the water passing this point on the first day of the 30-day period originated upstream 30 days earlier. Therefore, the meteorological conditions that determine downstream daily water temperatures on the first day are not included in the time period averages. In fact, only the last day's water column was influenced entirely by the meteorologic data used as input for the time period.

One way to overcome this problem is to redefine the time periods as smaller increments (as small as a day, if necessary) and track each day's water column movement using the previous day's results as the initial conditions for the current day.

Diurnal Fluctuations

The following relationships can be solved explicitly at any study site or point of interest to determine the maximum temperature rise of the water above the average. They are based on the fact that the water temperature equals the average temperature twice each day, that the average water temperature occurs approximately half way through the day, and that the remainder of the day the water temperature increases steadily to a maximum close to sunset. The same logic is used to determine the minimum water temperature by substituting nighttime conditions in lieu of daytime conditions:

$$d = \{[(Q/\bar{B})n]/[\sqrt{S_e}]\}^{3/5} \qquad \text{II(113)}$$

$$t_x = (S_o/2)\ 3600 \quad \text{II(114)}$$

$$T_{ox} = T_{ed} - \{(T_{ed} - T_{wd}) \exp [(K_d t_x)/(\rho c_p d)]\} \quad \text{II(115)}$$

$$T_{wx} = T_{ex} - \{(T_{ex} - T_{ox}) \exp [-(K_x t_x)/(\rho c_p d)]\} \quad \text{II(116)}$$

where d ≡ average flow depth (m)

n ≡ Manning's n-value

Q ≡ discharge (cms)

$\bar{B}$ ≡ average top width (m)

S_e ≡ energy gradient (m/m)

t_x ≡ travel time from noon to sunset (sec)

S_o ≡ duration of possible sunshine from sunrise to sunset (hours)

T_{ed} ≡ equilibrium temperature for average daily conditions (C)

T_{ex} ≡ equilibrium temperature for average daytime conditions (C)

T_{wd} ≡ average daily water temperature (at solar noon) at point of interest (C)

T_{ox} ≡ average daily water temperature at travel time distance upstream from point of interest (C)

T_{wx} ≡ average maximum daytime water temperature (at sunset) at point of interest (C)

K_d ≡ first order thermal exchange coefficient for daily conditions ($J/m^2/sec/C$)

K_x ≡ first order thermal exchange coefficient for daytime conditions, $J/m^2/sec/C$

ρ ≡ density of water = 1000 kg/m^3

c_p ≡ specific heat of water = 4182 J/kg/C

Because of the symmetry assumed for the daytime conditions, it is only necessary to calculate the difference between the maximum daytime and average daily water temperatures to obtain the minimum water temperature:

$$T_{wn} = T_{wd} - (T_{wx} - T_{wd}) \qquad II(117)$$

where T_{wn} ≡ average minimum nightime water temperature (at sunrise) at point of interest (C)

T_{wx} ≡ average maximum daytime water temperature (at sunset) at point of interest (C)

T_{wd} ≡ average daily water temperature (at solar noon) at point of interest (C)

Flow Mixing

The equation for determining the final downstream water temperature when flows of different temperatures and discharges meet is:

$$T_J = (T_B Q_B + T_T Q_T)/(Q_B + Q_T) \qquad II(118)$$

where T_J ≡ water temperature below junction

T_B ≡ water temperature above junction on the mainstem (branch node)

T_T ≡ water temperature above junction on the tributary (terminal node of the tributary)

Q_B ≡ discharge above junction on the mainstem (branch node)

Q_T ≡ discharge above junction on the tributary (terminal node on the tributary)

REGRESSION MODELS

Regression models are commonly used to smooth data and/or fill in missing data. They are used as a part of the instream water temperature model to provide initial water temperatures at headwaters or point sources to start the transport mode and as an independent prediction of water temperatures at interior network points for purposes of validation and calibration. Obviously, regression models are only useful at the points of analysis and cannot be used in lieu of the longitudinal heat transport model. Two regression models are included in the instream water temperature model package: (1) a standard regression model; and (2) a transformed regression model. Each model requires measured or known water temperatures as the dependent variable, along with associated meteorological, hydrological, and stream geometry independent parameters. However, the standard regression model requires less detail than the transformed model. The standard model is satisfactory for most applications, but the transformed version has a better physical basis. The choice becomes a matter of judgement.

Standard Regression Model

IFG studies during model development showed that the following simple linear multiple regression model provides a high degree of correlation for natural conditions:

$$\hat{T}_w = a_0 + a_1 T_a + a_2 W_a + a_3 R_h + a_4 (S/S_o) + a_5 H_{sx} + a_6 Q$$

$$+ b_1 T_a^2 + b_2 W_a^2 + b_3 R_h^2 + b_4 (S/S_o)^2 + b_5 H_{sx}^2 + b_6 Q^2 \qquad \text{II(119)}$$

where $\hat{T}_w$ ≡ estimate of water temperature (C)

a_0-a_6 ≡ regression coefficients for linear independent variables

b_1-b_6 ≡ regression coefficients for second-order independent variables

T_a ≡ air temperature (C)

W_a ≡ wind speed (mps)

R_h ≡ relative humidity (decimal)

S/S_o ≡ sunshine ratio (decimal)

H_{sx} ≡ extra-terrestrial solar radiation ($J/m^2/sec$)

Q ≡ discharge (cms)

It is recommended that the meteorological parameters and the solar radiation at the meteorological station be used for each regression analysis. Obviously, the discharge, Q, and the dependent water temperature variables must be obtained at the point of analysis.

These six independent variables are readily obtainable and are also necessary for the transport model. A minimum of seven data sets are necessary to obtain a solution, if the second-order terms are neglected. However, a greater number is desirable for statistical validity. Also, it needs to be emphasized that the resulting regression model is only valid at the point of analysis and only if upstream hydrologic conditions do not change. For example, if a reservoir has been constructed upstream subsequent to the data set, the model is not likely to be valid because the release temperatures have been affected.

Transformed Regression Model

The best regression model is one that not only uses the same parameters as the best physical-process models, but has the same, or nearly the same, mathematical form. That is, the regression model equation uses physical-process transformed parameters as the independent variables. This transformed regression model uses all of the input parameters used in the transport model except for stream distance and initial water temperature.

The first-order approximation of the constant-discharge heat transport model was chosen as the basis for the physical-process regression model. Water temperature and discharge data at the specified location, together with the corresponding time period meteorologic data from a nearby station, are needed. The meteorologic data is used to determine the equilibrium temperature (T_e) and first-order thermal exchange coefficient (K_1). The T_e and K_1 are combined with the corresponding time period discharges as independent variables to determine the regression coefficients for estimating the corresponding time period water temperature dependent variable. An estimate of the average stream width $\bar{B}$ above the site location is necessary as an arbitrary constant in the regression. The resulting regression coefficients are tantamount to synthetically determining an upstream source water temperature as a function of time and the distance to the source.

The constant discharge heat transport model is:

$$T_w = T_o + (T_e - T_o)\ \{1-\exp[-(K_1 \bar{B} x_o)/(\rho c_p Q)]\} \qquad \text{II(120)}$$

where
T_e ≡ equilibrium water temperature (C)
T_o ≡ initial water temperature (C)
T_w ≡ water temperature at x_o (C)
K_1 ≡ first-order thermal exchange coefficient ($J/m^2/sec/C$)
$\bar{B}$ ≡ average stream width (m)
x_o ≡ distance from T_o (m)
ρ ≡ water density = 1000 kg/m^3
c_p ≡ specific heat of water = 4182 J/kg
Q ≡ discharge (cms)

The definition of exp (x) = e^x is:

$$e^x = 1 + x + x^2/2! + x^3/3! + \cdots \qquad \text{II(121)}$$

If T_o is a function of the time period only, then it can be approximated as:

$$T_o = \bar{T}_o + \Delta T_o \cos[(2\pi/365)\ (D_i - 213)] \qquad \text{II(122)}$$

where
$\bar{T}_o$ ≡ average initial water temperature over all time periods (C)
ΔT_o ≡ half initial temperature range over all time periods (C)
D_i ≡ average Julian day for i^{th} time period; January 1 = 1 and December 31 = 365

Let $\quad Z_1 = -\,(K_1\overline{B})/(\rho c_p Q)$ II(123)

$$Z_2 = -T_e \tag{II(124)}$$

$$Z_3 = \cos\left[(2\pi/365)\ (D_i - 213)\right] \tag{II(125)}$$

If equations II(122) through II(125) are substituted into equation II(120), using II(121), and the terms rearranged, then T_w can be expressed as:

$$\begin{aligned} T_w = {} & T_0 + (\Delta T_0)Z_3 + (T_0 x_0)Z_1 + (\Delta T_0 x_0)Z_1 Z_3 \\ & + (x_0)Z_1 Z_2 + (\overline{T}_0{}^2 x_0{}^2/2)Z_1{}^2 + (\Delta T_0 x^2/2)Z_1{}^2 Z_3 \\ & + (x_0{}^2/2)Z_1{}^2 Z_2 + (\overline{T}_0 x_0{}^3/6)Z_1{}^3 + (\Delta T_0 x_0{}^3/6)Z_1{}^3 Z_3 \\ & + (x_0{}^3/6)Z_1{}^3 Z_2 + (\overline{T}_0 x_0{}^4/24)Z_1{}^4 + (\Delta T_0 x_0{}^4/24)Z_1{}^4 Z_3 \\ & + (x_0{}^4/24)Z_1{}^4 Z_2 + \cdots \end{aligned} \tag{II(126)}$$

If the converging power series is truncated after the final fourth-order term and the following substitutions are made, a possible multiple linear regression model results.

Let $\quad a_0 = \overline{T}_0$

$a_1 = \Delta T_0$	$X_1 = Z_3$
$a_2 = \overline{T}_0 x_0$	$X_2 = Z_1$
$a_3 = \Delta T_0 x_0$	$X_3 = Z_1 Z_3$
$a_4 = x_0$	$X_4 = Z_1 Z_2$
$a_5 = \overline{T}_0 x_0{}^2/2$	$X_5 = Z_1{}^2$

$$a_6 = \Delta T_0 x_0^2/2 \qquad X_6 = Z_1^2 Z_3$$

$$a_7 = x_0^2/2 \qquad X_7 = Z_1^2 Z_2$$

$$a_8 = \overline{T}_0 x_0^3/2 \qquad X_8 = Z_1^3$$

$$a_9 = \Delta T_0 x_0^3/6 \qquad X_9 = Z_1^3 Z_3$$

$$a_{10} = x_0^3/6 \qquad X_{10} = Z_1^3 Z_2$$

$$a_{11} = \overline{T}_0 x_0^4/2 \qquad X_{11} = Z_1^4$$

$$a_{12} = \Delta T_0 x_0^4/24 \qquad X_{12} = Z_1^4 Z_3$$

$$a_{13} = x_0^4/24 \qquad X_{13} = Z_1^4 Z_2$$

If the resulting independent transformed variables X_1 through X_{13} are regressed on the dependent variable T_w, the following regression equation results:

$$\hat{T}_w = a_0 + a_1 X_1 + \cdots + a_{13} X_{13} \qquad \text{II(127)}$$

The best estimates of the synthetic physical-process parameters are:

$$\overline{T}_0 = a_0 \qquad \text{II(128)}$$

$$\Delta T_0 = a_1 \qquad \text{II(129)}$$

$$x_0 = a_2/a_0 \qquad \text{II(130)}$$

VALIDATION

Regression Model Validation

There were fifteen U.S. Geological Survey (USGS) gages within the Upper Colorado River Basin (UCRB) study area that had some useful instream water temperature data. However, none of the gage data were developed from accurate 24-hour averages. The USGS published temperatures can be assumed only to represent water temperatures somewhere between the minimum and maximum on the day recorded. Frequently, published temperature data were missing for several days a month at each gage. Therefore, accurate monthly means of the average daily water temperature for a specific year at any given gage were not obtainable.

The transformed regression model was used at each gage to smooth the data. The published water temperature data were treated as the dependent variable. The corresponding discharge and prevailing meteorological parameters obtained from published data at the Grand Junction weather station were transformed into the independent variables. Data from 1964 through 1979 were used for the regression.

Table II.4 identifies the respective gages and their associated adjusted correlation coefficients (R) and probable difference (δ). The correlation coefficient is the ratio of explained variation of the predicted temperature to the total variation of the published temperature. The probable difference is the expected difference range of the published temperature with respect to the predicted temperatures; i.e., 50% of the published temperatures fall within the probable difference limits of the predicted temperature.

The regression models for the headwater gages were used to determine the initial water temperatures necessary for the instream water temperature transport model. The regression models for the validation/calibration gages were used to calibrate and measure the performance of the transport model.

Table II.4. Transformed regression model statistics.

USGS gage name and number	Location	R	δ (C)
Headwater gages			
Flaming Gorge 09234500	Green River near Greendale, UT	.7304	1.17
Maybell 09251000	Yampa River near Maybell, CO	.9483	1.78
Lily 09260000	Little Snake River near Lily, CO	.9505	1.74
Duschesne 09302000	Duschesne River near Randett, UT	.9682	1.32
Watson 09306500	White River near Watson, UT	.9764	1.13
Price 09314500	Price River at Woodside, UT	.8950	2.82
San Rafael 09328500	San Rafael River near Green River, UT	.9791	1.21
Cameo 09095500	Colorado River near Cameo, CO	.9567	1.90
Dolores 09180000	Dolores River near Cisco, UT	.9818	1.07
Grand Junction 09152500	Gunnison River near Grand Junction, CO	.9864	0.74
Validation/calibration gages			
Jensen 09261000	Green River near Jensen, UT	.9799	0.91
Green River 09315000	Green River near Green River, UT	.9838	1.07
State line 09163530	Colorado River near CO-UT State line	.9808	0.99
Cisco 09180500	Colorado River near Cisco, UT	.9876	0.84
UT163 09182880	Colorado River at UT163 near Moab, UT	.9802	1.20

Heat Transport Model Validation

The regression models for the validation gages were compared to the heat transport model (Theurer and Voos 1982). Table II.5 gives the mean difference (Δ) and probable difference range (δ), before calibration, by months for the years 1964 to 1979. Table II.6 gives the same statistics for "normal" discharges and meteorological conditions. The probable difference range is the 50% confidence limits about the mean difference; i.e., 50% of the data from the validation gage regression model will fall within $\Delta \pm \delta$ of the transport model.

Care must be taken not to assume that the differences represent errors. Where there is a difference, it can only be said that both temperatures cannot be correct. Errors do exist in both the regression and transport models because they are simply models. However, validation of the models, as also shown here, suggests a high degree of reliability and indicates that the first area to look for improvement in any given application is the input data set for the specific application. It has been pointed out that the published water temperature data do not necessarily represent the average daily water temperatures (Theurer and Voos 1982). Therefore, it can only be expected that the regression model predictions generally fall within the minimum/maximum daily water temperatures. See Theurer et al. (1982) for a discussion of application of the model.

CALIBRATION

Calibration is defined as adjusting one or more input parameters or internally-defined model coefficients to meet certain specified objective functions. Desirable objective functions include eliminating the mean errors, minimizing the square of the errors, or both. A well defined objective function is subject to the number of independent data sets available, the number of input parameters or internal coefficients considered as candidates, and, of course, the tractability of solution. The instream water temperature model includes two calibration models: (1) ground level solar radiation; and

Table II.5. Heat transport model statistics for 1964-1979 before calibration (after Theurer and Voos 1982).

		Jensen	Green River	State line	Cisco	UT163
January	Δ	0.78	0.21	- 0.04	0.05	- 0.60
	δ	± 0.57	± 0.41	± 0.29	± 0.11	± 0.51
February	Δ	0.44	0.27	- 0.16	- 0.04	- 0.31
	δ	± 0.59	± 0.51	± 0.57	± 0.54	± 0.92
March	Δ	0.70	0.46	0.21	- 0.08	0.30
	δ	± 0.59	0.37	± 0.51	± 0.35	± 0.53
April	Δ	0.10	0.19	- 0.13	- 0.10	0.82
	δ	± 0.74	± 0.37	± 0.90	± 0.68	± 0.54
May	Δ	- 1.96	- 1.01	0.00	0.39	- 0.73
	δ	± 0.91	± 0.57	± 0.49	± 0.48	± 0.78
June	Δ	- 1.46	- 1.48	- 0.55	- 0.11	- 1.77
	δ	± 0.80	± 0.57	± 0.43	± 0.41	± 0.94
July	Δ	0.12	- 1.78	- 0.74	- 0.35	- 1.23
	δ	± 1.03	± 0.52	± 0.53	± 0.55	± 0.66
August	Δ	- 0.26	- 1.67	- 0.66	- 0.56	- 0.75
	δ	± 0.94	± 0.32	± 0.41	± 0.52	± 0.63
September	Δ	- 0.01	- 0.97	- 0.58	- 0.70	- 1.03
	δ	± 0.80	± 0.38	± 0.68	± 0.63	± 0.62
October	Δ	- 0.13	- 0.91	- 0.28	- 0.72	- 0.79
	δ	± 0.47	± 0.45	± 0.38	± 0.51	± 1.03
November	Δ	0.06	- 0.90	- 0.86	- 1.17	- 1.84
	δ	± 0.53	± 0.34	± 0.37	± 0.44	± 0.78
December	Δ	0.76	- 0.21	- 1.03	- 0.97	- 2.64
	δ	± 0.71	± 0.36	± 0.35	± 0.35	± 0.86
Annual	Δ	- 0.08	- 0.65	- 0.40	- 0.35	- 0.84
	δ	± 0.91	± 0.67	± 0.56	± 0.55	± 0.92

Table II.6. Heat transport model statistics, normals before calibration (after Theurer and Voos 1982).

		Jensen	Green River	State line	Cisco	UT163
January	Δ	1.11	0.00	0.27	0.25	- 0.88
February	Δ	0.76	0.52	0.02	- 0.14	- 1.01
March	Δ	0.92	0.65	0.25	- 0.10	- 0.03
April	Δ	0.61	0.39	0.18	0.11	0.45
May	Δ	- 1.19	- 0.49	0.15	0.63	- 0.46
June	Δ	- 1.36	- 1.24	- 0.13	0.55	- 1.63
July	Δ	0.52	- 1.48	- 0.18	0.19	- 1.05
August	Δ	0.52	- 1.49	- 0.26	- 0.70	- 0.49
September	Δ	0.36	- 1.13	- 0.64	- 1.03	- 1.50
October	Δ	0.17	- 0.71	- 0.32	- 0.99	- 1.85
November	Δ	- 0.10	- 1.07	- 0.96	- 1.46	- 2.64
December	Δ	0.54	- 0.65	- 1.11	- 1.26	- 3.38
Annual	Δ	0.24	- 0.56	- 0.23	- 0.33	- 1.21
	δ	± 0.53	± 0.53	± 0.31	± 0.49	± 0.73

(2) transport model water temperature predictions. Of course, regression models automatically include calibration concepts as their mathematical basis; i.e., least squares or minimizing the square of the errors, as well as no net mean error.

Solar Calibration

Solar radiation can be calibrated at ground level by using SOLMET data. The U.S. Department of Energy has compiled and summarized (Cinquemani et al. 1978) several years of solar radiation data at many weather stations throughout the United States. Normal solar radiation at ground level by months is available. These data can be used to calibrate the dust and/or ground reflectivity coefficients. Table II.7 shows the monthly normal meteorology at the Grand Junction weather station, together with a summary of the measured solar radiation. Initial estimates of the dust and ground reflectivity coefficients were made from Tables II.1 and II.2 and adjusted by trial and error until satisfactory agreement with the published solar data was reached. The resulting final values of dust and ground reflectivity are assumed to be valid over the UCRB without change from year to year. However, the changes between time periods are maintained.

Table II.7. Solar calibration using normal meteorology.

Monthly normals at Grand Junction $d_1 = 0.10$

Lat: 39° 07' Elev: 1476 m $d_2 = 0.20$

1	2	3	4	5	6	7	8	9	10	11
	C	dec.	dec.	J/m²/sec	J/m²/sec	dec.	dec.	dec.	dec.	dec.
Time period	T_a	R_h	S/S_o	H_{sg}	H_{sx}	$e^{-\eta z}$	1-a'	a"	d	R_g
Jan	- 3.0	0.718	0.58	103.9	184.8	.7374	.1711	.7254	.1989	.1899
Feb	0.9	0.590	0.64	147.0	243.4	.7556	.1530	.7448	.1989	.2539
Mar	5.1	0.475	0.64	204.1	325.7	.7840	.1368	.7640	.1925	.3707
Apr	10.9	0.400	0.67	260.9	407.7	.7830	.1295	.7725	.1797	.2941
May	16.8	0.363	0.71	312.6	464.7	.8009	.1306	.7692	.1613	.4025
June	21.8	0.295	0.79	342.4	486.6	.7937	.1317	.7671	.1389	.2812
July	25.9	0.328	0.78	324.5	473.5	.7779	.1443	.7464	.1137	.1614
Aug	24.1	0.345	0.76	286.6	425.7	.7742	.1458	.7450	.1128	.1269
Sep	19.6	0.363	0.79	241.0	350.7	.7751	.1473	.7454	.1381	.2269
Oct	12.7	0.430	0.74	176.7	265.3	.7761	.1562	.7372	.1607	.3346
Nov	4.3	0.570	0.63	120.6	196.4	.7741	.1709	.7234	.1791	.4045
Dec	- 1.4	0.680	0.60	96.1	166.6	.7444	.1797	.7160	.1922	.2503
annual	11.5	0.465	0.70	217.9	333.0	.7837	.1381	.7596	.1500	.2662

The meteorologic station at Grand Junction is located at latitude 39° 07' and elevation 1476 m. The dust coefficients (column 10) were determined from the annual cycle formula [equation II(19)] assuming $d_1 = 0.10$ and $d_2 = 0.20$. The monthly normal meteorological values in columns 2, 3, and 4 of Table II.7 were obtained from the 1977 Grand Junction, Colorado LCD's. The solar radiation data at ground level in column 5 were obtained from measured data (Cinquemani et al. 1978). The solar radiation parameters in columns 6, 8, and 9 were calculated using the HP-41C solar radiation model. The atmospheric attenuation coefficient in column 7 was calculated according to equation II(131). And finally, the ground reflectivity (column 11) was calibrated to reproduce the solar radiation at ground level according to equation II(132). Therefore, the final dust and ground reflectivity coefficients reproduce the normal solar radiation at ground level for normal meteorologic conditions and are assumed to be valid for the entire UCRB, regardless of the year simulated.

The following equations were used to supplement the HP-41C solar radiation model:

$$e^{-\eta z} = H_{sg}/\{[0.22 + 0.78(S/So)^{2/3}]H_{sx}\} \qquad \text{II(131)}$$

$$R_g = \{2-[(1-a'-d + 2a'')/e^{-\eta z}]\}/\{1-a' + d\} \qquad \text{II(132)}$$

Single-Parameter Heat Transport Calibration

It is possible to calibrate the heat transport model to closely match the mean water temperature data at any of the validation gages by adjusting a single, but significant, parameter. There are several candidate parameters within the meteorological (e.g., solar), hydrology (e.g., source temperature), and stream geometry variables (e.g., stream width). If the assumption is made that the validation gage regression models are accurate, one calibration technique would involve adjusting the wind speed to account for both the transposition of the wind speed from the weather station to each reach in the basin and to possibly better determine the evaporation coefficient used in the heat flux components.

Tables II.8 and II.9 show how a wind speed factor can be used to reduce or entirely eliminate the monthly mean differences, Δ, at validation gages. No attempt was made to calibrate UT163 because the data are considered unreliable. Obviously, if the mean differences for all months are reduced or eliminated at a specific gage, the annual mean difference is also reduced or eliminated. However, a probable difference range for each month will generally remain. In other words, calibration can only reduce the bias, not necessarily remove all differences.

Table II.8. Wind calibration factors.

	Jensen	Green River	State line	Cisco
January	1.85	1.6	1	1
February	1.22	1.05	0.94	1.05
March	1.3	1.08	1.06	0.8
April	1.06	1.07	0.95	1
May	0	0.83	1	1.7
June	0	0.75	0.7	1.5
July	1.08	0.505	0.79	1.05
August	0.76	0.65	0.85	0.9
September	1	0.715	0.85	0.78
October	0.9	0.62	0.9	0.4
November	1.02	0.34	0.6	0
December	1.3	0.48	0.4	0.6

Note: The input wind speed at each node was set equal to the associated wind calibration factor times the wind speed at the meteorological station for the proper year and time period. Nodes were associated with the first radiation/calibration node encountered downstream.

Table II.9. Statistics of heat transport model after single-parameter (wind) calibration: 1964-1974.

		Jensen	Green River	State line	Cisco	UT163
January	Δ	0.01	0.09	- 0.04	0.05	- 0.60
	δ	± 0.31	± 0.22	± 0.29	± 0.11	± 0.51
February	Δ	0.00	0.01	- 0.01	- 0.04	- 0.30
	δ	± 0.59	± 0.47	± 0.57	± 0.54	± 0.92
March	Δ	0.00	0.01	0.02	- 0.01	0.62
	δ	± 0.55	± 0.38	± 0.51	± 0.34	± 0.57
April	Δ	0.01	- 0.04	0.03	- 0.01	0.88
	δ	± 0.73	± 0.37	± 0.90	± 0.67	± 0.54
May	Δ	- 1.37	- 0.01	0.00	0.05	- 1.43
	δ	± 1.19	± 0.82	± 0.49	± 0.65	± 0.61
June	Δ	- 0.46	- 0.02	0.00	- 0.00	- 2.04
	δ	± 1.46	± 0.67	± 0.53	± 0.44	± 0.80
July	Δ	0.01	0.06	- 0.01	0.04	- 1.10
	δ	± 0.99	± 0.48	± 0.55	± 0.51	± 0.65
August	Δ	0.00	- 0.04	- 0.02	0.01	- 0.21
	δ	± 1.12	± 0.30	± 0.44	± 0.52	± 0.65
September	Δ	- 0.01	0.00	- 0.03	- 0.02	- 0.17
	δ	± 0.80	± 0.38	± 0.70	± 0.64	± 0.66
October	Δ	0.06	- 0.00	- 0.02	- 0.04	0.42
	δ	± 0.47	± 0.35	± 0.36	± 0.46	± 0.92
November	Δ	0.02	0.00	- 0.02	0.02	- 0.16
	δ	± 0.54	± 0.29	± 0.34	± 0.38	± 0.69
December	Δ	0.00	- 0.04	0.00	- 0.05	- 1.52
	δ	± 0.76	± 0.36	± 0.28	± 0.27	± 0.69
Annual	Δ	- 0.15	0.00	- 0.01	0.01	- 0.47
	δ	± 0.87	± 0.44	± 0.51	± 0.47	± 0.89

Table II.10 shows the monthly mean differences at each validation gage for the normal (mean monthly average) calibrated conditions. They could have just as easily been calibrated on the normals and the results compared to the historical temperatures.

Table II.10. Statistics of heat transport model after single-parameter (wind) calibration: normals.

		Jensen	Green River	State line	Cisco	UT163
January	Δ	- 0.28	0.00	0.27	0.25	- 0.88
February	Δ	0.27	0.21	0.15	- 0.06	- 0.99
March	Δ	0.20	0.18	0.08	- 0.06	0.23
April	Δ	0.50	0.17	0.33	0.20	0.53
May	Δ	- 0.56	0.65	0.15	0.37	- 1.04
June	Δ	- 0.55	0.26	0.35	0.75	- 1.72
July	Δ	0.40	- 0.07	0.35	0.57	- 0.79
August	Δ	0.95	0.17	0.35	- 0.15	0.10
September	Δ	0.36	- 0.09	- 0.07	- 0.53	- 1.02
October	Δ	0.38	0.30	0.01	- 0.23	- 0.55
November	Δ	- 0.15	- 0.06	- 0.08	- 0.21	- 0.88
December	Δ	- 0.22	- 0.41	0.02	- 0.13	- 2.25
Annual	Δ	0.11	0.11	0.16	0.06	- 0.77
	δ	± 0.31	± 0.18	± 0.11	± 0.25	± 0.53

Multiple-Parameter Heat Transport Calibration

The single-parameter calibration scheme can only eliminate bias (mean error) or only minimize the standard deviation of the errors, for example. The multiple-parameter scheme can not only eliminate bias but also can minimize the probable differences. By spreading the amount of calibration over multiple parameters, no single variable requires as much change as they do in the single-parameter scheme. This latter feature reduces the tendency of the final calibrated values to exceed reasonable, or even physical, limits.

If known water temperature data are available, together with matching time period meteorological data for several time periods, then multiple-parameter calibration of either or both the regression and heat transport models is possible. The objective of calibration of the regression model is to minimize the probable differences because the mean difference is automatically zero. However, the objective of calibration of the heat transport model is twofold; first, to eliminate bias (set the mean differences to zero) and, second, to minimize the probable differences.

The multiple-parameter heat transport calibration scheme is based on the first-order solution of the constant discharge heat transport model, the same as the transformed regression model.

Element Correction

A first-order correction formula for a single element from a paired data set is:

$$T_{wi} - \hat{T}_{wi} = (\partial T_w/\partial z_1)\Delta z_1 + (\partial T_w/\partial z_2)\Delta z_2 + \cdots + (\partial T_w/\partial z_n)\Delta z_n \qquad \text{II(133)}$$

where T_{wi} ≡ ith known water temperature

$\hat{T}_{wi}$ ≡ ith predicted water temperature

z_i thru z_n ≡ ith dummy variables to represent an n-dimensional multiple-parameter data set

In order to linearize equation II(133) and to more easily apply constraints, the individual dummy corrections (Δz_i) are noted as:

$$\Delta z_i = b_{0,i} + b_{1,i}\, z_i \qquad \text{II(134)}$$

where Δz_i ≡ ith dummy correction term

z_i ≡ ith actual value dummy term

$b_{0,i}$ ≡ ith calibration constant

$b_{1,i}$ ≡ ith calibration factor

Partial Derivatives

In order to solve the correction formula, it is necessary to determine the partial derivatives for each of the calibration parameters. These derivatives are based on the heat transport equation:

$$T_w = T_o + (T_e - T_o)\ [1\text{-}\exp(\bullet)] \qquad \text{II(135)}$$

where $\exp(\bullet) = \exp[-(K_1 x_o \overline{B})/(\rho c_p Q)]$

T_o is determined by:

$$T_o = T_e - [(T_e - T_w)/\exp(\bullet)] \qquad \text{II(136)}$$

where $T_w \equiv$ known water temperature

T_e and $\exp(\bullet)$ are calculated using current input data

The parameter x_o can be obtained from the original transformed regression model analysis and is treated as a given constant during calibration; ρ and c_p are physical constants. Q is treated as an independent given variable not subject to calibration. This leaves T_e, K_1, and $\overline{B}$ subject to calibration. The average stream width is a function of, at most, discharge. However, T_e and K_1 are functions of many physical constants and parameters. Only seven parameters are considered significant for calibration. They are:

$$T_e = f_1\ (H_{sw}, T_a, W_a, R_h, \overline{B}, S_h, K_g/\Delta Z_g)$$

$$K_1 = f_2\ (W_a, K_g/\Delta Z_g)$$

Because of the mathematical relationship between some of the physical constants and parameters, one parameter may serve as a surrogate for others. For example, wind speed (W_a) and the evaporation coefficient (C_b) are not separable. Also, ground temperature (T_g) and the streambed thermal gradient ($K_d/\Delta Z_g$) are surrogates for each other.

The change in water temperature with respect to any dummy variable is:

$$\partial T_e/\partial z = \{[(T_e+273.16)^4(\partial A/\partial z)] + [T_e(\partial B/\partial z)]$$

$$+ [(1.0640^{T_e})(\partial C/\partial z)] - [\partial D/\partial z]\}/-K_1 \qquad \text{II(137)}$$

$$\partial \exp(\bullet)/\partial z = [-x_o/(\rho c_p Q)][\exp(\bullet)]\{[\bar{B}(\partial K_1/\partial z)] + [K_1(\partial \bar{B}/\partial z)]\} \qquad \text{II(138)}$$

$$\partial K_1/\partial z = \{[12A(T_e+273.16)^2 + C(1.0640^{T_e})\ln^2(1.0640)][\partial T_e/\partial z]\}$$

$$+ \{\partial B/\partial z\} + \{[(1.0640^{T_e})\ln(1.0640)][\partial C/\partial z]\}$$

$$+ \{[4(T_e+273.16)^3 (\partial A/\partial z)]\} \qquad \text{II(139)}$$

$$\partial T_w/\partial z = \{[1-\exp(\bullet)][\partial T_e/\partial z]\} - \{[T_e-T_o][\partial \exp(\bullet)/\partial z]\} \qquad \text{II(140)}$$

$$\partial \bar{B}/\partial z = I[z = \bar{B}] \qquad \text{II(141)}$$

where

$$A = 5.40\bullet 10^{-8} \qquad \text{II(142)}$$

$$B = [C_c\ C_e\ P] + [K_g/\Delta Z_g] \qquad \text{II(143)}$$

$$C = C_e \qquad \text{II(144)}$$

$$D = H_a + H_f + H_s + H_v$$

$$+ [C_c\ C_e\ PT_a]$$

$$+ [T_g(K_g/\Delta Z_g)]$$

$$+ [C_e\ R_h\ (1.0640^{T_a})] \qquad \text{II(145)}$$

$$C_e = a + bW_a + cW_a^2 \qquad \text{II(146)}$$

$$C_c = B_f/6.60 \qquad \text{II(147)}$$

$$H_a = (1-S_h)(1 + 0.17C_\ell^2)[3.36 + 0.706\ (R_h \cdot 1.0640^{T_a})^{1/2}]$$

$$[10^{-8}(T_a + 273.16)^4] \qquad \text{II(148)}$$

$$H_f = [9805\ (Q/\bar{B})\ S_f] \qquad \text{II(149)}$$

$$H_s = [(1-S_h)\ H_{sw}] \qquad \text{II(150)}$$

$$H_v = [(5.24 \cdot 10^{-8})\ S_h\ (T_a + 273.16)^4] \qquad \text{II(151)}$$

let $$H_a' = [(1-S_h)\ (1 + 0.17C_\ell^2)\ (3.36 \cdot 10^{-8})\ (T_a + 273.16)^4] \qquad \text{II(152)}$$

when $z_1 = H_{sw}$:

$$\partial\bar{B}/\partial H_{sw} = 0 \qquad \text{II(153)}$$

$$\partial A/\partial H_{sw} = 0 \qquad \text{II(154)}$$

$$\partial B/\partial H_{sw} = 0 \qquad \text{II(155)}$$

$$\partial C/\partial H_{sw} = 0 \qquad \text{II(156)}$$

$$\partial D/\partial H_{sw} = (1-S_h) \qquad \text{II(157)}$$

when $z_2 = T_a$:

$$\partial\bar{B}/\partial T_a = 0 \qquad \text{II(158)}$$

$$\partial A/\partial T_a = 0 \qquad \text{II(159)}$$

$$\partial B/\partial T_a = 0 \qquad \text{II(160)}$$

$$\partial C/\partial T_a = 0 \qquad \text{II(161)}$$

$$\partial D/\partial T_a = [4(H_a + H_v)/(T_a + 273.16)]$$

$$+ \{[(H_a - H_a')/2]\ [\ell n(1.0640)]\}$$

$$+ [C_c\ C_e\ P]$$

$$+ [C_e\ \ell n(1.0640)(1.0640^{T_a})] \qquad \text{II(162)}$$

when $z_3 = W_a$:

$$\partial \overline{B}/\partial W_a = 0 \qquad \text{II(163)}$$

$$\partial A/\partial W_a = 0 \qquad \text{II(164)}$$

$$\partial B/\partial W_a = C_c\ [b + 2\ cW_a]\ P \qquad \text{II(165)}$$

$$\partial C/\partial W_a = b + 2\ cW_a \qquad \text{II(166)}$$

$$\partial D/\partial W_a = [C_c\ (b + 2\ cW_a)\ P] + [b + 2\ cW_a\ R_h\ (1.0640^{T_a})] \qquad \text{II(167)}$$

when $z_4 = R_h$:

$$\partial \overline{B}/\partial R_h = 0 \qquad \text{II(168)}$$

$$\partial A/\partial R_h = 0 \qquad \text{II(169)}$$

$$\partial B/\partial R_h = 0 \qquad \text{II(170)}$$

$$\partial C/\partial R_h = 0 \qquad \text{II(171)}$$

$$\partial D/\partial R_h = [(H_a - H_a')/(2\ R_h)] + [C_e\ (1.0640^{T_a})] \qquad \text{II(172)}$$

when $z_5 = K_g/\Delta Z_g$:

$$\partial \overline{B}/\partial (K_g/\Delta Z_g) = 0 \qquad \text{II(173)}$$

$$\partial A/\partial (K_g/\Delta Z_g) = 0 \qquad \text{II(174)}$$

$$\partial B/\partial (K_g/\Delta Z_g) = 1 \qquad \text{II(175)}$$

$$\partial C/\partial (K_g/\Delta Z_g) = 0 \qquad \text{II(176)}$$

$$\partial D/\partial (K_g/\Delta Z_g) = T_g \qquad \text{II(177)}$$

when $z_6 = \bar{B}$:

$$\partial\bar{B}/\partial\bar{B} = 1 \qquad \text{II(178)}$$

$$\partial A/\partial\bar{B} = 0 \qquad \text{II(179)}$$

$$\partial B/\partial\bar{B} = 0 \qquad \text{II(180)}$$

$$\partial C/\partial\bar{B} = 0 \qquad \text{II(181)}$$

$$\partial D/\partial\bar{B} = -H_f/\bar{B} \qquad \text{II(182)}$$

when $z_7 = S_h$:

$$\partial\bar{B}/\partial S_h = 0 \qquad \text{II(183)}$$

$$\partial A/\partial S_h = 0 \qquad \text{II(184)}$$

$$\partial B/\partial S_h = 0 \qquad \text{II(185)}$$

$$\partial C/\partial S_h = 0 \qquad \text{II(186)}$$

$$\partial D/\partial S_h = (H_v/S_h) - [(H_a + H_s)/(1-S_h)] \qquad \text{II(187)}$$

The objective function is:

$$\Delta_j = \hat{T}_{w,j} - T_{w,j}$$

$$x_i = (\partial T_w/\partial z_i)\ [I(k_i=1) + z_i I(l_i=1)]$$

then

$$\Delta_j = c_1 x_{1,j} + c_2 x_{2,j} + \cdots + c_n x_{n,j}$$

where $c_i = b_{o,i} I(k_i=1) + b_{1,i} I(l_i=1)$

$k_i = 0$ if ith constant is zero, 1 otherwise

$l_i = 0$ if ith factor is zero, 1 otherwise

to eliminate bias:

$$\sum_{j=1}^{J} [\Delta_j - (c_1 x_{1,j} + c_2 x_{2,j} + \cdots + c_n x_{n,j})] = 0 \qquad \text{II(189)}$$

To minimize the probable differences:

$$\text{Min. : } S = \sum_{j=1}^{J} [\Delta_j - (c_1 x_{1,j} + c_2 x_{2,j} + \cdots + c_n x_{n,j})]^2 \qquad \text{II(190)}$$

requires

$$\partial S/\partial c_i = 0$$

therefore

$$S = [\Delta - (c_1 x_1 + c_2 x_2 + \cdots + c_n x_n)]^2$$

$$= [\Delta_1 - (c_1 x_1 + c_2 x_{2,1} + \cdots + c_n x_{n,1})]^2$$

$$+ [\Delta_2 - (c_1 x_{1,2} + c_2 x_{2,2} + \cdots + c_n x_{n,2})]^2 + \cdots$$

$$+ [\Delta_j - (c_1 x_{1,j} + c_2 x_{2,j} + \cdots + c_n x_{n,j})]^2$$

$$\partial S/\partial c_i = \sum_{j=1}^{J} \{2\, x_{i,j} [\Delta_j - (c_1 x_{1,j} + c_2 x_{2,j} + \cdots$$

$$+ c_1 x_{1,j} + c_n x_{n,j})] = 0 \qquad \text{II(191)}$$

and

$$\Sigma\, [\Delta_j - (c_1 x_1 + c_2 x_2 + \cdots + c_n x_n)] = 0$$

becomes

$$\Sigma\Delta_j = c_1\, \Sigma\, x_1 + c_2\, \Sigma\, x_2 + \cdots + c_n\, \Sigma\, x_n \qquad \text{II(192)}$$

and

$$\Sigma\Delta_j\, x_i = c_1\, \Sigma(x_1 x_i) + c_2\, \Sigma(x_2 x_i) + \cdots + c_i\, \Sigma x_i^2 + \cdots + c_n\, \Sigma[x_i x_n)]$$

The above probable difference equations can be expressed in matrix form as:

$$\begin{bmatrix} \Sigma(x_1^2) & \Sigma(x_1x_2) & \cdots & \Sigma(x_1x_n) \\ \Sigma(x_2x_1) & \Sigma(x_2^2) & \cdots & \Sigma(x_2x_n) \\ \vdots & \vdots & & \vdots \\ \Sigma(x_nx_1) & \Sigma(x_nx_2) & \cdots & \Sigma(x_n^2) \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} \begin{matrix} = \\ = \\ \vdots \\ = \end{matrix} \begin{bmatrix} \Sigma(x_1\Delta) \\ \Sigma(x_2\Delta) \\ \vdots \\ \Sigma(x_n\Delta) \end{bmatrix} \qquad \text{II(193)}$$

and the bias equation is:

$$c_1 \, \Sigma \, x_1 + c_2 \, \Sigma \, x_2 + \cdots + c_n \, \Sigma \, x_n = \Sigma\Delta \qquad \text{II(194)}$$

the solution of which eliminates bias and minimizes the probable differences. If all seven parameters are chosen for calibration, a minimum of seven data sets are required; more are required if both the constant and factor calibration terms for any parameter are nonzero.

The solution of the above multiple-parameter calibration scheme is dependent on which equation is eliminated from the set of equations. If the first equation (bias equation) is eliminated, a residual bias will remain, but the probable differences will be at the absolute minimum. The elimination of one of the probable differences equations locates the bias equation in the matrix. This will eliminate bias but will have a different probable difference for each choice for the eliminated equation. The best choice will depend on both the magnitude of the errors and the range of the regression coefficients. For example, the wind coefficient should not be less than 0 because negative winds have no physical meaning.

STATISTICAL DEFINITIONS

A small set of statistical parameters are used to measure the performance of various portions of the instream water temperature model. The coefficient of multiple correlation (R) and the probable difference (δ) are used as the measures of performance of the regression model. The mean difference (Δ) and probable difference (δ) are used as the measures of performance of the physical-process model at validation and calibration points within the network.

The standard deviation (S_T) and modified standard difference of estimate ($S_{T.X}$) are intermediate statistical parameters used to calculate the probable difference. All measurements are for temperature; therefore, the units are Celcius except for R, which is dimensionless.

Standard Deviation

The standard deviation is a measure of the dispersion or variation of published water temperature data about its mean. All standard deviations calculated by this model are modified to give the best estimate of the population standard deviation from the set of published temperature (sample) data. Consequently, this parameter is, by convention, the sample standard deviation. The formula is:

$$S_T = \sqrt{[\Sigma(T_i - \bar{T})^2]/[N-1]} \qquad \text{II(195)}$$

where S_T ≡ standard deviaton of sample set (C)

T_i ≡ ith published temperature from sample set (C)

$\bar{T}$ ≡ mean temperature of sample set = $\Sigma T_i/N$ (C)

N ≡ number of temperatures in sample set

Modified Standard Difference of Estimate

The modified standard difference of estimate is analogous to the standard deviation. It is a measure of the dispersion of the differences between the published temperatures and the predicted regression model values and between the predicted regression and heat transport models. The standard differences calculated by this model are modified by the number of degrees of freedom used. The number of degrees of freedom, when comparing the regression model to the physical-process model, is reduced by calibration. The number of degrees of freedom used, when comparing published temperatures to predicted regression model values, is the number of terms used in the regression model; e.g., a single-independent variable regression model has two terms, and a two-independent variable multiple regression model has three terms.

Convention usually calls this parameter the standard error of estimate. However, there are errors in using the published recorded water temperatures (even when "smoothed") as accurate estimates of the average daily water temperature, as well as inherent errors in any prediction model. The typical published water temperatures are assumed to be taken at some variable unknown time of day and represent, at best, a water temperature somewhere between the minimum and the maximum of the diurnal cycle. If the published temperatures were really taken at random times, then use of the regression model would "smooth" or approach the 24-hour average. However, the most that reasonably can be assumed is that the heat transport model will generally predict temperatures that fall within the diurnal temperature cycle, about the predicted value from the regression model, and, maybe, the mean differences between the two will be minimized (calibration).

Heat Transport Model

The formula for the best estimate of the standard difference of estimate for the heat transport model is:

$$S_{T.X} = \sqrt{[\Sigma\ (T_j - T_i)^2]/[N-1]} \qquad \text{II(196)}$$

where $S_{T.X}$ ≡ modified standard difference of estimate (C)

T_j ≡ jth predicted temperature from regression model (C)

T_i ≡ ith predicted temperature from heat transport model (C)

N ≡ number of temperatures in sample set

$i = j$

Regression Model

The formula used for the best estimate of the standard difference of estimate for the regression model is an alternate form of equation II(196):

$$S_{T.X} = S_T \sqrt{[(1-R^2)\ (N-1)]/[N-n]} \qquad \text{II(197)}$$

where $S_{T.X}$ ≡ modified standard difference of estimate (C)

S_T ≡ standard deviation of sample set (C)

R ≡ coefficient of multiple correlation

N ≡ number of temperatures in sample set

n ≡ number of terms in regression model

Coefficient of Multiple Correlation

The coefficient of multiple correlation is a measure of the explained variation to the total variation. This definition is only valid when the variations are about the same mean. Therefore, the coefficient of multiple correlation is only applicable to the regression model because the mean of the predicted heat transport temperatures is generally different from the mean of the published water temperatures. The formula is:

$$R = \sqrt{[\Sigma(T_i - \bar{T})^2]/[\Sigma(T_j - \bar{T})^2]} \qquad \text{II(198)}$$

where R ≡ coefficient of multiple correlation

T_j ≡ jth published temperature from sample set (C)

T_i ≡ ith predicted temperature from regression model (C)

$\bar{T}$ ≡ mean temperature of sample set (C)

$i = j$

Mean Difference

The mean difference is the average of the differences between the predicted regression and heat transport models. The mean difference of the regression model, with respect to the published temperatures, is automatically zero because of the mathematical restrictions imposed by the regression conditions. However, the heat transport model, when compared to predicted regression model temperatures, generally has a bias because of independent errors inherent in both. One purpose of calibration is to eliminate these mean differences. The formula is:

$$\Delta = [\Sigma(T_i - T_j)]/N \qquad \text{II(199)}$$

where Δ ≡ mean difference (C)

T_j ≡ jth predicted temperature from regression model (C)

T_i ≡ ith predicted temperature from heat transport model (C)

N ≡ number of predicted temperatures in sample set

$i \equiv j$

Probable Difference

The probable difference is used to determine how well the various models are performing. It sets the 50% confidence limits; i.e., 50% of the actual water temperatures fall within $\Delta \pm \delta$ of the model predictions. Again, for the regression model Δ always equals zero; generally, Δ does not equal zero for the heat transport model. Without calibration, the formula is:

$$\delta = 0.6745\ S_{T.X} \qquad \text{II(200)}$$

where δ ≡ probable difference (C)

$S_{T.X}$ ≡ modified standard difference of estimate (C)

CONVERSIONS AND PHYSICAL CONSTANTS

The standard units used for the water temperature model are metric units. In addition, all physical constants and internal processing algorithmns are computed using metric units. However, for user convenience, the input/output model portions of the computer model have a user-specified option that allows the user to request English units. This option requires that all standard input/output displays be in English units. Internal processing, which is transparent to the user, remains in metric units. If the English units option is specified, then: (1) the computer input model converts all English units to metric units; (2) the computer processing model performs the necessary calculations in metric units; and (3) the computer output model converts the metric units to English units for output display. Note that only the computer model has an English units option. The other solution techniques (HP-34C and HP-41C), because of their limited processing capabilities, operate entirely in metric units. Table II.11 can be used to convert commonly used English units to standard metric units.

The physical constants in the instream water temperature model range from well established constants used in physics (e.g., the solar constant) to empirically-derived coefficients (e.g., the evaporation coefficient). The physics constants have a single value for any situation. However, the empirically-derived coefficients frequently are expressed as a range of possible values. Table II.12 gives the single-valued constants and the chosen constant value for empirically-derived coefficients.

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Table II.11. Equivalent English and metric units.

Parameter	English units	Equivalent metric units
H_{sr}	1 BTU/ft²/day	0.1313 J/m²/sec
	1 langley/day	0.4842 J/m²/sec
	1 kcal/m²/day	0.04842 J/m²/sec
	1 KJ/m²/day	0.01157 J/m²/sec
W	1 ft/sec	0.3048 m/sec
	1 mile/hr	0.4470 m/sec
p	1 in H_g	33.86 mb
	1 mm H_g	1.333 mb
	1 psi	68.95 mb
	1 atm	1013.00 mb
v	1 ft/sec	0.3048 m/sec
d	1 ft	0.3048 m
q	1 ft²/sec	0.09290 m²/sec
Q	1 ft³/sec	0.02832 m³/sec
A	1 ft²	0.09290 m²
T	1 T_F	$32 + [(9/5)T_C]$

Table II.12. Physical constants.

Parameter	Physical constants
C_b	evaporation coefficient, $1 \le C_b \le 5$; use $C_b = 1.681$
C_T	adiabatic temperature correction coefficient; use $C_T = -0.00656$ C/m
c_p	specific heat of water = 4182 J/kg/C
e	orbital eccentricity = 0.0167238 decimal
K_g	thermal conductivity coefficient; use $K_g = 1.65$ J/m/sec/C for water-saturated sands and gravel mixtures
k	type of cloud cover factor, $0.04 \le k \le 0.24$; use k = 0.17
q_s	solar constant = 1377 J/m^2/sec
r_ℓ	longwave radiation reflection; use $r_\ell = 0.03$ decimal
T_{ab}	absolute zero correction = 273.16 C
ρ	density of water = 1000 kg/m^3
σ	Stefan-Boltzman constant = $5.672 \cdot 10^{-8}$ J/m^2/sec/K^4
ε_w	water emissivity; use $\varepsilon_w = 0.9526$ decimal
ε_v	vegetation emissivity; use $\varepsilon_v = 0.9526$ decimal

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INSTREAM WATER TEMPERATURE MODEL
Part III. User's Manual

Fish and Wildlife Service

U.S. Department of the Interior

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PART III. USER'S MANUAL

GENERAL INPUT REQUIREMENTS

Input data for the instream temperature model consist of three distinct parts: (1) stream system geometry; (2) meteorology; and (3) hydrology. The meteorological data can be obtained from available published data for areas near the stream basin; e.g., from local airports or Weather Bureau stations. These data are transferred over the stream basin using standard hydrology lapse rate corrections. All four solution techniques require the above input parts; however, each technique requires different amounts of input massaging prior to entry.

Stream System Geometry

The stream system geometry consists of: (1) the stream network plan-view; (2) the stream network elevation-profile; (3) the average stream widths for each reach; (4) the shade parameters for each reach; and (5) an estimate of the hydraulic retardence (n-values) for each reach.

The stream network can be represented as a line diagram. It must: (1) include all major tributaries with significant flows; (2) identify a logical sequence of flows; and (3) provide all necessary distances along the stream. The network may be as simple as a single reach or as complex as an entire river basin network. The complexity will be dictated by the upstream-downstream extent of study interest and downstream extent of availability of hydrology data. On ungaged tributaries, it may be necessary to go all the way upstream to the source and synthetically develop initial hydrologic data. Other situations may include a reservoir, which can be used as the upstream starting point for that particular tributary.

The elevation profile is needed to determine the average elevation above mean sea level and the bed slopes of each reach. The elevation above mean sea level for each reach is used to determine the atmospheric pressure and the adiabatic meteorological corrections.

The average stream widths play an important role in identifying each distinct reach. The heat exchange between the water and the surrounding environment is a function of the water surface area. Therefore, significant changes in average stream widths are indicators of necessary changes in stream reach definitions.

Shading has a noticable effect on equilibrium water temperatures. Therefore, changes in shading characteristics require separate reach definitions.

The hydraulic retardence is perhaps best expressed as an n-value. These n-values are used to determine travel times of the water columns and average flow depths. These parameters are only used to determine diurnal fluctuations.

Reaches should be defined as a part of the stream system network. They should reflect not only the important hydrological features (discontinuities, such as tributary junctions), but also major channel geometry changes, changes in shading, and elevation differences of no more than 1000 ft. This latter condition affects the local meteorological parameters.

Meteorology

Meteorology consists of: (1) station identification data; (2) certain climatologic synoptic data; and (3) dust and ground reflectivity coefficients for solar radiation parameters. Both the synoptic and solar data must be summarized for the time periods chosen for analysis.

If the average daily water temperature for the first week of June, 1975, is desired, then the corresponding input must be for the first week of June, 1975. If average daily water temperatures are desired for the entire month of July, 1975, then the input data must also be averaged for July, 1975. If mean average daily August water temperatures are needed, then the mean average

August input data are needed. Average, as used here, is defined as the arithmetic average of the pertinent parameters during a specified year for the time period to be analyzed. Mean, as used here, is defined as the arithmetic average of the pertinent parameters over the years of record for the time period to be analyzed.

The station identification consists of the latitude and elevation of the station above mean sea level. The latitude is used for solar radiation computations; the elevation is needed as a reference for the lapse rate corrections of the synoptic data. It is assumed that the station is close enough to the stream basin to represent the same meteorological conditions over the time period chosen for analysis. If orographic conditions result in weather station data in a stream basin that are different on one side of a mountain range from the other side, then meteorological data must be obtained from another source. Measured solar radiation at the ground level for several locations in the United States (see Fig. III.1) can be found in Cinquemani et al. (1978).

The synoptic data consist of the mean annual air temperature and the time period averages for air temperature, relative humidity, relative sunshine, and wind speed. These data can be obtained from various sources; e.g., local airports and published weather bureau reports. If monthly time periods are suitable, local climatological data (LCD) can be obtained for several locations from the U.S. Department of Commerce in Asheville, NC. The LCD's contain daily, monthly, or annual data for the year requested. Each request must specify the type of LCD desired.

Hydrology

The hydrology data consist of: (1) the initial discharges at all the upstream limits of the stream system network; (2) the lateral flows for each reach; (3) any internal network diversions and return flows; and (4) the initial water temperatures for all upstream limits, lateral inflows, return flows, point flows, reservoir releases, and validation/calibration node discharges. The hydrology data must be averaged over the same time period as the meteorology data.

STATION NETWORK

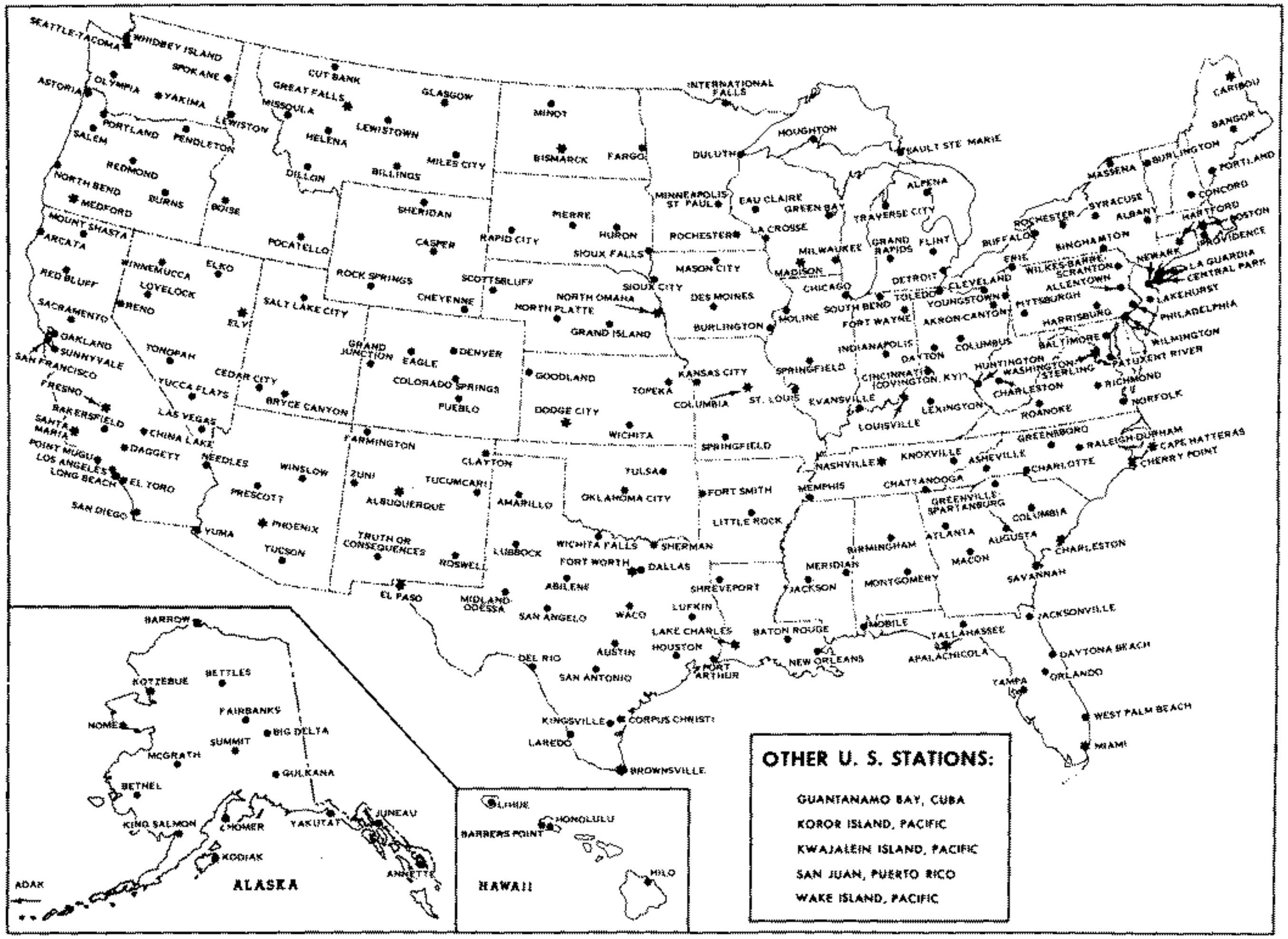

Figure III.1. Location of mean monthly ground level solar data stations (see Cinquemani et al. 1978 for data).

The initial discharges and lateral flows should be determined from acceptable hydrologic procedures that account for conservation of mass. They can be based on historical records, synthetic procedures, or a combination of these sources. Reservoir operational procedures and/or management for diversions and return flows can be incorporated into the hydrologic model. The U.S. Geological Society (USGS) published data and their WATSTOR data bank are convenient sources of historical data.

Initial water temperatures at all headwaters and point sources are necessary data. Naturally occurring initial temperatures can be developed from regression analysis if data are available or developed synthetically by applying the instream water temperature model upstream from the desired starting point. Outflows from man-controlled structures, such as reservoirs, may require an *a priori* reservoir operations schedule that shows discharge-temperature data for the desired time period. It is possible to model reservoir impoundments with a depth-temperature relationship, but the reservoir operation schedule for discharge-withdrawal level information is still necessary.

The water temperature of incoming lateral flow (ground water) is usually close to the mean annual air temperature for the reach. Departures from this temperature occur in special situations, such as "hot spring" areas. Obviously, outgoing lateral flows (losing streams) have the same temperature as the stream. The transport model automatically recognizes this fact.

Diversions have the same temperature as the stream at the point of diversion; however, return flows can have a different temperature, depending on the use of the water. Surface irrigation return flows are likely to be close to the equilibrium water temperature; otherwise, they can be treated the same as ground water. The temperature of other kinds of return flows (e.g., waste water) must be estimated or measured.

HP-34C SOLUTION TECHNIQUE

The HP-34C program requires the most preprocessing of input data prior to use. Initially, eight basic input meteorological-associated parameters are needed:

1. H_{sg} ≡ solar radiation ($J/m^2/sec$)
2. C_ℓ ≡ cloud cover (decimal)
3. S_h ≡ shade (decimal)
4. T_a ≡ air temperature (C)
5. W_a ≡ wind speed (mps)
6. R_h ≡ relative humidity (decimal)
7. P ≡ atmospheric pressure (mb)
8. T_g ≡ ground temperature (C)

The HP-34C program solves the heat flux relationship for the equilibrium water temperature (friction is ignored) and the first-order thermal exchange coefficient associated with the above input meteorological conditions.

Subsequently, the following hydrologic and stream geometry basic input parameters are needed:

T_o ≡ initial or starting water temperature (C)
x_o ≡ downstream distance (km)
Q_o ≡ stream discharge (cms)
$\bar{B}$ ≡ average stream width (m)

The HP-34C program solves the constant discharge ($q_\ell = 0$) first order solution of the transport equation. The result is the average daily water temperature at the end of a reach X_o km downstream when the water entering is at T_o. This solution technique can be repeated an unlimited number of times as long as the equilibrium temperature and first-order thermal exchange coefficient are not changed.

The procedure is:

1. Clear HP-34C of all other program steps.
2. Load HP-34C program (as listed in Part IV).
3. Input the eight basic parameters as follows:

Reg.	Parameter
0	H_{sg}
1	C_ℓ
2	S_h
3	T_a
4	W_a
5	R_h
6	P
I	T_g

4. Execute "A".
5. Record output:

   K_1 is in x register

   T_e is in y register

6. Input hydrologic and geometric parameters:

Reg Stack	Input Parameter
t	T_o
z	x_o
y	Q_o
x	$\bar{B}$

7. Execute "B".

8. Record T_w as display in x register.

9. Repeat steps 6 through 8 as desired to change hydrology and geometry parameters.

10. Repeat steps 3 through 9 as desired to change meteorology parameters.

HP-34C Example

	Variable	Reg.	Stack
Input:	H_{sg} = 255.4 J/m²/sec	0	
	C_ℓ = 0.50	1	
	S_n = 0.30	2	
	T_a = 27 C	3	
	W_a = 3.66 m/sec	4	
	R_h = 0.30	5	
	P = 850 mb	6	
	T_g = 10 C	I	
Execute:	Sub A		
Output:	K_1 = 36.32 J/m²/sec/C	0	x
	T_e = 20.74 C	I	y
Input:	T_o = 9 C		t
	x_o = 30 km		z
	Q_o = 1.0 cms		y
	$\bar{B}$ = 10 m		x
Execute:	Sub B		

Output: T_w = 19.87 C; i.e., the average daily water temperature will be 19.87 C at a point 30 km downstream from T_o = 9 C when the discharge in the stream is 1.0 cms.

HP-41C SOLUTION TECHNIQUE

The HP-41C programs include a solution for every part of the instream water temperature model because the individual parts of the model were first developed, verified, and tested using the HP-41C. These individual parts have been integrated into five operational programs for field use: (1) solar shade; (2) solar radiation; (3) standard multiple regression; (4) transformed regression; and (5) heat transport. The source code listing and availability information can be found in Part IV of this report.

These programs are designed for stand alone capability; together, they provide a complete potential solution for any instream water temperature study. Furthermore, the separate programs can be used as subsidiary solutions for the other solution techniques; e.g., the HP-41C solar shade program can be used to determine the input shade factor for the other solution techniques.

This particular solution technique can be used to solve water temperature studies of intermediate complexity where the volume of calculations does not preclude manual calculations. Most field problems are in this category. However, large river basin studies that involve interagency coordination and/or open-ended "gaming" probably lend themselves more towards the FORTRAN 77 solution technique.

The HP-41C minumum required hardware configuration for the programs is:

1. HP-41C.
2. Quad memory module.
3. Math Pac.
4. Printer.
5. Card reader.

The 320 registers (provided with the Quad memory modules) and the printer are needed by all of the programs. The Math Pac is used only by the regression programs, and the card reader is used only to load the programs.

The following explanations presume familiarity with the HP-41C.

Solar Shade Program

This program determines the topographic and riparian vegetation shade factors. Topographic shade results from the influence of the local topography on the actual sunrise/sunset times. Riparian vegetation shade consists of shadows cast on the water by vegetation near or along the streambanks between the actual sunrise and sunset. The shade model calculates the actual solar radiation intercepted by each source of shade and expresses the shade factor as a ratio of the intercepted amount of solar radiation divided by the total potential amount.

The shade program allows the user to specify up to 12 time periods and the topographic and vegetative shade parameters for up to three reaches at a time. Independent physical shade parameters are expected input for each side of the stream. If there is no essential difference between sides, the same parameters may be used for each side.

For each requested time period and reach, the solar shade program predicts the time-averaged: (1) local combined sunrise/sunset altitude; (2) topographic shade factor; (3) riparian shade factor; and (4) total shade factor. The total shade factor is needed as input when using the HP-41C transport program. When using the HP-41C program as a subsidiary to the computer program, minimum/maximum total shade factors are needed as input to the computer program. The shade option choice depends on the intended use of the computer program.

There are five kinds of necessary stream geometry input data for each reach: (1) latitude; (2) stream azimuth; (3) average stream width; (4) topographic altitude angle; and (5) riparian vegetation parameters.

The stream reach latitude (ϕ) locates the reach on the globe and is readily obtained from many sources, such as a USGS quad sheet. It is used together with the time of year to track the sun.

The stream reach azimuth (A_r) orients the general stream direction and, in the northern hemisphere, is always referenced from due south. If the stream meanders greatly, the analysis can be separated into multiple steps (subreaches) and the results combined for a weighted stream reach average. The stream azimuth is important to orient the shadows with respect to the water surface.

The average stream width ($\bar{B}$) is the same value used in the transport program. It is necessary to define what portion of the shadows are relevant; i.e., only the shadows on the water are pertinent to the model.

The topographic altitude angle (α_s) is the vertical angle from a level line at the streambank to the general top of the local terrain at right angles to the stream reach azimuth. It can be obtained easily either from field measurements or from spot-check calculations using USGS quad sheets. It is used to determine local sunrise and sunset times.

The riparian vegetation parameters consist of four basic vegetative values: (1) crown measurement; (2) height; (3) offset; and (4) density.

Crown measurement (V_c) is a function of crown diameter and accounts for overhang. Crown measurement is the average of the maximum diameter of the vegetation immediately adjacent to the stream.

Height (V_h) is the average maximum existing or proposed height of the overstory vegetation above the water surface. If this height changes dramatically along the streambank (e.g., due to a change in vegetation), subdividing the reach into smaller subreaches may be warranted.

Offset (V_o) is the average distance of the tree trunks from the water's edge. It is used, together with the crown measurement, to determine net overhang.

Density (V_d) is a measure of the screening of the sunlight that would otherwise pass through the shaded area. It accounts for both the continuity of riparian vegetation along the stream bank and the filtering effect of leaves and stands of trees along the stream. For example, if only 50% of the streamside has riparian vegetation and if this vegetation actually filters only 50% of the sunlight, then the density is 0.25.

Control over the selection of time periods is entirely up to the user. The user can select predefined time periods by months or define their own. If the user selects the month option, they can select a month (single month) or group of months (month loop). The daily increment to be used must be specified by the user. Obviously, 1-day increments are the most precise, but are not always warranted. If the user selects the 1-day time period option, they can do only one time period grouping at a time; however, they still select the daily increment.

The user also can select whether to use an annual distribution of vegetation density or to provide the density directly for each reach. If the annual distribution option is selected, the user must provide the yearly minimum and maximum values for each reach and stream side. The model calculates the actual value as a function of the Julian day. The minimum value is assumed in the winter, the maximum in the summer, and leaf-out and fall in the spring and autumn respectively. If the other option is chosen, no variation in time is assumed for that particular run.

The solar shade program prompts for all input. The following variable name list defines each input/output variable involved. During the input sequence, numbers appear as a part of the variable name. They pertain to the reach identification number. East and west bank designations are referenced according to the stream azimuth; i.e., looking south, regardless of the direction of the flow. Therefore, the left-hand side is always the east bank and the right-hand side is the west bank. This is still true for a due east orientation (azimuth of -90°); the left-hand or north side, by convention, is designated the east bank.

The variable name list (in typical sequential order) is:

INPUT

LAT ≡ latitude (degrees.minutes)

AR ≡ stream reach azimuth (degrees.minutes)

B ≡ average stream width (m)

aTE ≡ eastside topographic altitude (degrees.minutes)

VCE ≡ eastside crown measurement (m)

VHE ≡ eastside height (m)

VOE ≡ eastside offset (m)

VDE ≡ eastside density (decimal)

aTW ≡ westside topographic altitude (degrees.minutes)

VCW ≡ westside crown measurement (m)

VHW ≡ westside height (m)

VOW ≡ westside offset (m)

VDW ≡ westside density (decimal)

OUTPUT (time period averages)

aS ≡ local composite sunrise/sunset altitude (degrees.minutes)

ST ≡ topographic shade factor (decimal)

SV ≡ riparian vegetation shade factor (decimal)

SH ≡ total shade factor (decimal)

The procedure to use the solar shade program is:

1. Clear the HP-41C.
2. Execute "SIZE 057".
3. Load the solar shade program.
4. ASN "S H A D E" Σ+.

5. Execute "SHADE" by keying Σ+.

6. Repeat step 5 as needed.

Example. A stream reach is located at a latitude of 42° 30' N and is oriented from northeast to southwest at 30° 20' azimuth. It is in a mountainous valley that has a topographic altitude of 25° on both sides. These measurements were obtained from USGS quad sheets and have been confirmed in the field. The field trip also indicated that the west side is farmed, leaving no riparian vegetation. The east side is heavily forested with pine trees along the stream. The crown measurement is 6 m, the offset is 1.5 m, the average height is 9 m, and the left bank has only 20% open space. Because the trees are several stands deep from the bank, 100% of the sunlight is filtered. Therefore, the left bank density is assumed to be a constant 0.80. Spot measurements in the field indicated that the average stream width is 10 m. The biologist is interested in a water temperature study because the stream is salmonid spawning habitat for steelhead, spring chinook, and fall chinook. Therefore, the biologist needs information from May through September and is willing to use monthly time periods. The engineer responsible for the study knows that 2-day increments are sufficiently precise for the shade calculation. The HP-41C printer tape (Fig. III.2) shows the input sequence and the corresponding output. The output is summarized as follows:

Month		Sunrise/set altitude (deg.min)	Shade factor (decimal)		
No.	Name		topo.	veg.	total
5	May	53.29	0.0907	0.3034	0.3945
6	June	55.37	0.0833	0.2937	0.3774
7	July	54.30	0.0886	0.2984	0.3856
8	Aug.	50.11	0.1016	0.3161	0.4180
9	Sep.	42.36	0.1279	0.3430	0.4711

While the output varies from May to September, there is not a large variation between successive months. Therefore, the 2-day increment was valid and probably could have been increased to 3 or even 4 days to reduce computation time.

```
     XEQ "SHADE"

TRACE:Y/N?
N
                                  RUN
ANGLES:D/R?
D                                 RUN
TIME PER:M/D?
M                                 RUN

LAT:D.M=?
                         42.30    RUN
AR:D.M=?
                         30.20    RUN
B:M=?
                         10.0     RUN
aTE:D.M=?
                         25.00    RUN
VCE:M=?
                           6.0    RUN
VHE:M=?
                           9.0    RUN
VOE:M=?
                           1.5    RUN
VDE:D=?
                           0.8    RUN
aTW:D.M=?
                         25.00    RUN
VCW:M=?
                             0
                             0    RUN
VHW:M=?
VOW:M=?                      0
                             0    RUN
VDW:D=?
                                  RUN

MONTH:NO.=?
                         5.009    RUN
INC:DAY=?
                             2    RUN
```

```
MONTH NO. 5
FROM: DAY=121
THRU: DAY=151

aS = 53.29 D.M.
ST = 0.0911 D
SW = 0.3034 D
Sh = 0.3945 D

MONTH NO. 6
FROM: DAY=152
THRU: DAY=181

aS= 55.37 D.M.
ST = 0.0838 D
SV = 0.2937 D
SH = 0.3774 D

MONTH NO. 7
FROM: DAY=182
THRU: DAY=212

aS = 54.38 D.M.
ST = 0.0872 D
SV = 0.2984 D
SH = 0.3856 D

MONTH NO. 8
FROM: DAY=213
THUR: DAY=243

aS = 50.11 D.M.
ST = 0.1019 D
SV = 0.3161 D
SH = 0.4180 D

MONTH NO. 9
FROM: DAY=244
THRU: DAY=273

aS = 42.36 D.M.
ST = 0.1281 D
SV = 0.3430 D
SH = 0.4711 D
```

Figure III.2. HP-41C shade input/output example.

Solar Radiation Program

This program can be used to calibrate the dust and ground reflectivity coefficients and predicts the extra-terrestrial solar radiation and other solar-related parameters needed by the other programs. Solar radiation is a well understood phenomena and can be readily modeled. Extra-terrestrial radiation is a function of latitude and time of year. It is attenuated as it passes through the atmosphere. The same meteorological parameters that are needed by the heat transport program are used to predict this attenuation. Dust and ground reflectivity are additional parameters that affect attenuation. Finally, the amount of solar radiation penetrating the water is a function of the solar altitude, which also is easily modeled. The solar radiation model calculates: (1) the time period average extra-terrestrial solar radiation; (2) the necessary intermediate parameters for the calibration of dust and ground reflectivity; (3) daylight duration; and (4) solar radiation at the ground level.

The solar program allows the user to specify up to 12 time periods and the pertinent stream geometry data for up to 10 reaches at a time. Two kinds of input are necessary: stream geometry data by reach and meteorology-related data by time period.

The stream geometry data consist of latitude, average reach elevation, and average sunrise/sunset altitude. The latitude (ϕ) locates the reach on the globe and is readily obtained from many sources, such as a USGS quad sheet. It is used together with the time of year to track the sun. The average reach elevation (Z_a) is also easily obtained from quad sheets. It is used for the adiabatic correction of the meteorological data due to elevation changes. The average sunrise/sunset altitude (α_s) can be estimated from field data or obtained from the output of the solar shade program. It is used to calculate the local daylight duration.

The meteorology-related data consists of some of the same meteorological data needed by the heat transport program, plus the dust and ground reflectivity coefficient.

The meteorological data are the mean daily air temperature (T_a), relative humidity (R_h), and sunshine ratio (S/S_o). They can be obtained from many sources, such as monthly summaries published by NOAA. The dust and ground reflectivity coefficients (d and R_g) can be estimated from the tables found in Part II of this report or calibrated using published solar data (Cinquemani et al. 1978). The meteorological data must correspond to the elevation specified for the first reach. Subsequent reaches correct the meteorology data with respect to the elevation difference between the first and current reaches.

Control over the selection of time periods is entirely up to the user. The user can select predefined time periods by months or define their own. If the user selects the month option, they can then select a month (single month) or group of months (month loop). The daily increment to be used must be specified by the user. Obviously, 1-day increments are the most precise, but are not always warranted. If the user selects his own time period option, only one time period grouping at a time is done; however, he still selects the daily increment.

The user can select whether to use an annual distribution of dust and ground reflectivity or to provide the coefficients directly for each time period. The former option calculates the individual coefficients on a daily basis and determines a time period average. The latter option assumes that the coefficients are constant over the specified time period. If the annual distribution option is selected, the user must provide the yearly minimum and maximum values. The annual distributions are as described in Part II of this report. No spatial variation is assumed for either coefficient; i.e., they are assumed to be a constant for the basin for the current time period.

The solar radiation program prompts for all input. The following variable name list defines each input/output variable involved. During the input sequence, numbers appear as a part of the variable name. When creating reach data, the numbers pertain to the reach identification number. When creating time period data, the numbers pertain to the time period identification number.

The variable name list (in typical sequential order) is:

INPUT

LAT ≡ latitude (degrees.minutes)

ELEV ≡ stream reach elevation (meters above sea level)

aS ≡ sunrise/sunset altitude (degrees.minutes)

TA ≡ air temperature (C)

RH ≡ relative humidity (decimal)

S/S_o ≡ sunshine ratio (decimal)

d ≡ dust coefficient (decimal)

RG ≡ ground reflectivity coefficient (decimal)

OUTPUT (time period averages)

HSX ≡ extra-terrestrial solar radiation ($J/m^2/sec$)

1-AP ≡ first calibration parameter (decimal)

AAP ≡ second calibration parameter (decimal)

a ≡ average solar altitude (radians)

d ≡ dust coefficient (decimal)

RG ≡ ground reflectivity coefficient (decimal)

HSG ≡ ground level solar radiation ($J/m^2/sec$)

The procedure to use the solar radiation program is:

1. Clear the HP-41C.
2. Execute "SIZE 124".
3. Load the solar radiation program.
4. ASN "S O L R A D" Σ+.
5. Execute "SOLRAD" by keying Σ+.
6. Repeat step 5 as needed.

Example. An interagency study is proposed for the Upper Colorado River Basin (UCRB). The U.S. Fish and Wildlife Service has determined that water temperature impacts will be studied. Therefore, the instream water temperature model computer program solution technique will be linked with other models for the purpose of gaming. Part of the data set necessary for the link are calibrated dust and ground reflectivity coefficients. Published monthly solar radiation and meteorological data are available for the Grand Junction, Colorado, weather station.

The Grand Junction station is at latitude 39° 07' and 1476 m in elevation. The scientist reponsible for the calibration has determined that the annual distribution of the dust coefficient can be used with a minimum value = 0.10 and a maximum value = 0.20. Only the ground reflectivity will be calibrated for each month. However, temporary values of ground reflectivity were assumed in order to execute the radiation component. These temporary values are minimum value = 0.20 and maximum value = 0.40.

The data are presented in Table III.1. Columns 2, 3, and 4 were obtained from the published 1977 Local Climatological Data (LCD) Monthly Summaries for Grand Junction. Column 5 was taken from published solar data (Cinquenmani et al. 1978). Columns 8 and 9 were output from the solar radiation component. The sunrise/sunset altitude at the meteorological station is close to zero. The atmospheric attenuation coefficient (Column 7) was calculated according to:

$$e^{-\eta z} = H_{sg}/\{[0.22 + 0.78(S/S_o)^{2/3}]H_{sx}\}$$

The ground reflectivity was calibrated to reproduce the ground level solar radiation according to:

$$R_g = \{2-[(1-a'-d + 2a'')/e^{-\eta z}]\}/\{(1-a' + d)\}$$

Table III.1. Dust and ground reflectivity.

Monthly normals at Grand Junction $d_1 = 0.10$

Lat: 39° 07' Elev: 1476 m $d_2 = 0.20$

1	2	3	4	5	6	7	8	9	10	11
	C	dec.	dec.	J/m²/sec	J/m²/sec	dec.	dec.	dec.	dec.	dec.
Time period	T_a	R_h	S/S_o	H_{sg}	H_{sx}	$e^{-\eta z}$	1-a'	a"	d	R_g
Jan	- 3.0	0.718	0.58	103.9	184.8	.7374	.1711	.7254	.1989	.1899
Feb	0.9	0.590	0.64	147.0	243.4	.7556	.1530	.7448	.1989	.2539
Mar	5.1	0.475	0.64	204.1	325.7	.7840	.1368	.7640	.1925	.3707
Apr	10.9	0.400	0.67	260.9	407.7	.7830	.1295	.7725	.1797	.2941
May	16.8	0.363	0.71	312.6	464.7	.8009	.1306	.7692	.1613	.4025
June	21.8	0.295	0.79	342.4	486.6	.7937	.1317	.7671	.1389	.2812
July	25.9	0.328	0.78	324.5	473.5	.7779	.1443	.7464	.1137	.1614
Aug	24.1	0.345	0.76	286.6	425.7	.7742	.1458	.7450	.1128	.1269
Sep	19.6	0.363	0.79	241.0	350.7	.7751	.1473	.7454	.1381	.2269
Oct	12.7	0.430	0.74	176.7	265.3	.7761	.1562	.7372	.1607	.3346
Nov	4.3	0.570	0.63	120.6	196.4	.7741	.1709	.7234	.1791	.4045
Dec	- 1.4	0.680	0.60	96.1	166.6	.7444	.1797	.7160	.1922	.2503
annual	11.5	0.465	0.70	217.9	333.0	.7837	.1381	.7596	.1500	.2662

The copy of the HP-41C printer tape shows the input sequence (Fig. III.3) and the corresponding output (Fig. III.4). The calculated ground level solar radiation matches the measured radiation.

The final dust and ground reflectivity coefficients are listed in Columns 10 and 11 for the month time periods. They are assumed to be valid for the entire basin, regardless of year.

Standard Regression Program

This program provides a simple multiple regression model at a specified point in the stream network when sufficient reliable water temperature data are known. The resulting regression model can be used to provide initial temperatures at exterior points in the network; i.e., at headwaters and point loads. The regression model can also be used for interior points; i.e., at validation and calibration gages.

It must be emphasized that regression models only provide water temperature predictions at the point where the measured water temperature data were obtained and only for the hydrologic and geometric conditions reflected by the measured data. The heat transport model is necessary for longitudinal water temperature predictions and to reflect changed hydrologic and stream geometry conditions.

The standard regression program uses the four basic meteorological parameters, the calculated extra-terrestrial solar radiation, and discharge as independent variables. The associated measured water temperature for the corresponding time period is the dependent variable. A simple linear multiple regression analysis, using least squares, is the basis for determining the regression coefficients. A minimum of seven data sets is necessary because there are six independent variables.

```
XEQ "SOLRAD"

TIME PER:M/D?
R/S MONTHS
D DAYS
                        RUN

d, RG:T/A?
R/S TIME PER.
A ANN. DIST.
A                       RUN

d MIN:D=?
              0.10      RUN
d MAX:D=?
              0.20      RUN

RG MIN:D=?
              0.20      RUN
RG MAX:D=?
              0.40      RUN

NO. REACHS=?
                 1      RUN

REACH NO. 1
LAT1:D.M=?
             39.07      RUN
ELEV1:M=?
             1476.      RUN
aS1:D.M=?
                 0      RUN

MONTHS:NO.=?
             1.012      RUN
INC:DAY=?
                 1      RUN

MONTH NO. 1
TA1:C=?
              -3.0      RUN
RH1:D=?
             0.718      RUN
S/S01:D=?
              0.58      RUN
```

```
MONTH NO. 2
TA2:C=?
               0.9      RUN
RH2:D=?
             0.590      RUN
S/S02:D=?
              0.64      RUN

MONTH NO. 3
TA3:C=?
               5.1      RUN
RH3:D=?
             0.475      RUN
S/S03:D=?
              0.64      RUN

MONTH NO. 4
TA4:C=?
              10.9      RUN
RH4:D=?
             0.400      RUN
S/S04:D=?
              0.67      RUN

MONTH NO. 5
TA5:C=?
              16.8      RUN
RH5:D=?
             0.363      RUN
S/S05:D=?
              0.71      RUN

MONTH NO. 6
TA6:C=?
              21.8      RUN
RH6:D=?
             0.295      RUN
S/S06:D=?
              0.79      RUN
```

Figure III.3. HP-41C solar radiation input example.

```
MONTH NO. 7
TA7:C=?
                              25.9    RUN
RH7:D=?
                             Ø.328    RUN
S/SØ7:D=?
                              Ø.78    RUN

MONTH NO. 8
TA8:C=?
                              24.1    RUN
RH8:D=?
                             Ø.345    RUN
S/SØ8:D=?
                              Ø.76    RUN

MONTH NO. 9
TA9:C=?
                              19.6    RUN
RH9:D=?
                             Ø.363    RUN
S/SØ9:D=?
                              Ø.79    RUN

MONTH NO. 1Ø
TA1Ø:C=?
                              12.7    RUN
RH1Ø:D=?
                             Ø.43Ø    RUN
S/SØ1Ø:D=?
                              Ø.74    RUN

MONTH NO. 11
TA11:C=?
                               4.3    RUN
RH11:D=?
                             Ø.57Ø    RUN
S/SØ11:D=?
                              Ø.63    RUN

MONTH NO. 12
TA12:C=?
                              -1.4    RUN
RH12:D=?
                             Ø.68Ø    RUN
S/SØ12:D=?
                              Ø.6Ø    RUN
```

Figure III.3. (concluded)

```
REACH NO. 1

MONTH NO. 1
FROM: DAY= 1
THRU: DAY= 31

HSX= 184.8 J/M2/S
1-AP=Ø.1711 D
APP= Ø.7254 D
a  = Ø.371Ø D
d  = Ø.1989 D
RG = Ø.3843 D
SØ = 9.597 HR
HSG= 1Ø7.9 J/M2/S

MONTH NO. 2
FROM: DAY= 32
THRU: DAY= 59

HSX= 243.4 J/M2/S
1-AP=Ø.153Ø D
APP= Ø.7448 D
a  = Ø.4533 D
d  = Ø.1989 D
RG = Ø.3976 D
SØ = 1Ø.524 HR
HSG= 151.Ø J/M2/S

MONTH NO. 3
FROM: DAY= 6Ø
THRU: DAY= 9Ø

HSX= 325.7 J/M2/S
1-AP=Ø.1368 D
APP= Ø.764Ø D
a  = Ø.5596 D
d  = Ø.1925 D
RG = Ø.3981 D
SØ = 11.75Ø HR
HSG= 2Ø5.1 J/M2/S

MONTH NO. 4
FROM: DAY= 91
THRU: DAY= 12Ø

HSX= 4Ø7.7 J/M2/S
1-AP=Ø.1295 D
APP= Ø.7725 D
a  = Ø.6517 D
d  = Ø.1795 D
RG = Ø.3853 D
SØ = 13.Ø57 HR
HSG= 264.8 J/M2/S

MONTH NO. 5
FROM: DAY= 121
THRU: DAY= 151

HSX= 464.2 J/M2/S
1-AP=Ø.13Ø6 D
APP= Ø.7692 D
a  = Ø.7ØØ5 D
d  = Ø.1613 D
RG = Ø.3598 D
SØ = 14.155 HR
HSG= 31Ø.5 J/M2/S

MONTH NO. 6
FROM: DAY= 152
THRU: DAY= 181

HSX= 486.6 J/M2/S
1-AP=Ø.1317 D
APP= Ø.7671 D
a  = Ø.7146 D
d  = Ø.1389 D
RG = Ø.3234 D
SØ = 14.7Ø4 HR
HSG= 344.4 J/M2/S
```

Figure III.4. HP-41C solar radiation output example.

MONTH NO. 7
FROM: DAY= 182
THRU: DAY= 212

HSX= 473.5 J/M2/S
1-AP=Ø.1443 D
APP= Ø.7464 D
a = Ø.7Ø86 D
d = Ø.1137 D
RG = Ø.2785 D
SØ = 14.436 HR
HSG= 329.6 J/M2/S

MONTH NO. 8
FROM: DAY= 213
THRU: DAY= 243

HSX= 425.7 J/M2/S
1-AP=Ø.1458 D
APP= Ø.745Ø D
a = Ø.6735 D
d = Ø.1128 D
RG = Ø.2274 D
SØ = 13.473 HR
HSG= 29Ø.4 J/M2/S

MONTH NO. 9
FROM: DAY= 244
THRU: DAY= 273

HSX= 35Ø.7 J/M2/S
1-AP=Ø.1473 D
APP= Ø.7454 D
a = Ø.5953 D
d = Ø.1381 D
RG = Ø.2248 D
SØ = 12.2Ø6 HR
HSG= 24Ø.9 J/M2/S

MONTH NO. 1Ø
FROM: DAY= 274
THRU: DAY= 3Ø4

HSX= 265.3 J/M2/S
1-AP=Ø.1562 D
APP= Ø.7372 D
a = Ø.4871 D
d = Ø.16Ø7 D
RG = Ø.2753 D
SØ = 1Ø.9Ø3 HR
HSG= 174.9 J/M2/S

MONTH NO. 11
FROM: DAY= 3Ø5
THRU: DAY= 334

HSX= 196.4 J/M2/S
1-AP=Ø.17Ø9 D
APP= Ø.7234 D
a = Ø.39ØØ D
d = Ø.1791 D
RG = Ø.32Ø7 D
SØ = 9.814 HR
HSG= 118.7 J/M2/S

MONTH NO. 12
FROM: DAY= 335
THRU: DAY= 365

HSX= 166.6 J/M2/S
1-AP=Ø.1797 D
APP= Ø.716Ø D
a = Ø.3449 D
d = Ø.1922 D
RG = Ø.3577 D
SØ = 9.293 HR
HSG= 98.1 J/M2/S

Figure III.4. (concluded)

The four meteorological parameters are the same ones required by the heat transport program. They do not need to be corrected for the elevation differences because the data at the station are used directly at the gage. The four parameters are: (1) air temperature (T_a); (2) wind speed (W_a); (3) relative humidity (R_h); and (4) sunshine ratio (S/S_o). Data for these parameters are all available from published meteorological sources, such as NOAA's LCD's.

The extra-terrestrial solar radiation value is obtained directly from the solar radiation program. Discharge data are usually available from the same sources as the measured water temperature data, generally USGS data sources.

The standard regression program prompts for all input, one data set at a time, with a minimum of seven data sets. The estimates of water temperature using the regression model are based on:

$$\hat{T}_w = x_1 + x_2 T_a + x_3 W_a + x_4 R_h + x_5 H_{sx} + x_6 (S/S_o) + x_7 Q$$

The variable name list (in sequential order) is:

INPUT

TA ≡ air temperature (C)

WA ≡ wind speed (m/sec)

RH ≡ relative humidity (decimal)

HSX ≡ extra-terrestrial solar radiation ($J/m^2/sec$)

S/SO ≡ sunshine ratio (decimal)

Q ≡ discharge (m^3/sec)

TW ≡ measured water temperature (C)

OUTPUT

X1 ≡ first regression coefficient

X2 ≡ second regression coefficient

X3 ≡ third regression coefficient

X4 ≡ fourth regression coefficient

X5 ≡ fifth regression coefficient

X6 ≡ sixth regression coefficient

X7 ≡ seventh regression coefficient

R ≡ coefficient of multiple correlation (decimal)

ST ≡ standard deviation of actual dependent variable data set (C)

ST.X ≡ standard deviation of the difference between the estimated and actual dependent variable data sets (C)

d ≡ probable error of estimate (C)

The procedure to use the standard regression program is:

1. Clear the HP-41C.
2. Execute "SIZE 086".
3. Load the standard regression program.
4. ASN "S T D R E G" Σ+.
5. ASN "C O R D A T" $\sqrt{x}$.
6. ASN "T W" LN.
7. Execute STDREG by keying Σ+.
8. Input all data sets.
9. Execute TW by keying LN.
10. Input independent variable data set to determine Tw.

If an incorrect data set is started, complete the operation and then execute CORDAT by keying $\sqrt{x}$ with identical incorrect data set to recover. Program will automatically return to input the correct data set. Remember, the Math Pac is needed for this program.

Example. A hydrology report is available that summarizes monthly average discharges and water temperatures in the Green River at a USGS gage near Jensen, Colorado, in the Upper Colorado River Basin (UCRB). A quick analysis is desired. The usual meteorology data also are available from published weather bureau data for Grand Junction, Colorado.

A copy of the HP-41C printer tape shows the input sequence (Fig. III.5) and the corresponding output (Fig. III.6). The resulting regression statistics are summarized as:

$$\hat{T}_w = x_1 + (x_2 T_a) + (x_3 W_a) + (x_4 R_h) + (x_5 H_{sx}) + [x_6 (S/S_o)] + (x_7 Q)$$

$$\begin{aligned} \text{with} \quad R &= 0.9999 \text{ (decimal)} \\ ST &= 6.954 \text{ (C)} \\ ST.X &= 0.072 \text{ (C)} \\ d &= 0.049 \text{ (C)} \end{aligned}$$

The above regression model is now available for the desired analysis.

```
XEQ "STDREG"
```

```
INPUT SET 1
TA:C=?
                -3.0     RUN
WA:M/S=?
                2.50     RUN
RH:DEC=?
               0.718     RUN
HSX:J/M2/S=?
               184.8     RUN
S/S0:DEC=?
                0.58     RUN
Q:CMS=?
               68.01     RUN
TW:C=?
                0.47     RUN

INPUT SET 2
TA:C=?
                 0.9     RUN
WA:M/S=?
                2.95     RUN
RH:DEC=?
               0.590     RUN
HSX:J/M2/S=?
               243.4     RUN
S/S0:DEC=?
                0.64     RUN
Q:CMS=?
               76.21     RUN
TW:C=?
                3.17     RUN

INPUT SET 3
TA:C=?
                 5.1     RUN
WA:M/S=?
                3.75     RUN
RH:DEC=?
               0.475     RUN
HSX:J/M2/S=?
               325.7     RUN
S/S0:DEC=?
                0.64     RUN
Q:CMS=?
               83.41     RUN
TW:C=?
                6.42     RUN
```

```
INPUT SET 4
TA:C=?
                10.9     RUN
WA:M/S=?
                4.29     RUN
RH:DEC=?
               0.400     RUN
HSX:J/M2/S=?
               407.7     RUN
S/S0:DEC=?
                0.67     RUN
Q:CMS=?
              148.64     RUN
TW:C=?
               10.15     RUN

INPUT SET 5
TA:C=?
                16.8     RUN
WA:M/S=?
                4.29     RUN
RH:DEC=?
               0.363     RUN
HSX:J/M2/S=?
               464.2     RUN
S/S0:DEC=?
                0.71     RUN
Q:CMS=?
              284.75     RUN
TW:C=?
               13.77     RUN

INPUT SET 6
TA:C=?
                21.8     RUN
WA:M/S=?
                4.38     RUN
RH:DEC=?
               0.295     RUN
HSX:J/M2/S=?
               486.6     RUN
S/S0:DEC=?
                0.79     RUN
Q:CMS=?
              279.81     RUN
TW:C=?
               17.11     RUN
```

Figure III.5. HP-41C standard regression input example.

```
INPUT SET 7                          INPUT SET 1Ø
TA:C=?                               TA:C=?
              25.9    RUN                          12.7    RUN
WA:M/S=?                             WA:M/S=?
              4.16    RUN                          3.53    RUN
RH:DEC=?                             RH:DEC=?
             Ø.328    RUN                         Ø.43Ø    RUN
HSX:J/M2/S=?                         HSX:J/M2/S=?
             473.5    RUN                         265.3    RUN
S/SØ:DEC=?                           S/SØ:DEC=?
              Ø.78    RUN                          Ø.74    RUN
Q:CMS=?                              Q:CMS=?
            118.Ø5    RUN                         67.71    RUN
TW:C=?                               TW:C=?
             2Ø.5Ø    RUN                         1Ø.55    RUN

INPUT SET 8                          INPUT SET 11
TA:C=?                               TA:C=?
              24.1    RUN                           4.3    RUN
WA:M/S=?                             WA:M/S=?
              4.Ø2    RUN                          2.95    RUN
RH:DEC=?                             RH:DEC=?
             Ø.345    RUN                         Ø.57Ø    RUN
HSX:J/M2/S=?                         HSX:J/M2/S=?
             425.7    RUN                         196.4    RUN
S/SØ:DEC=?                           S/SØ:DEC=?
              Ø.76    RUN                          Ø.63    RUN
Q:CMS=?                              Q:CMS=?
             71.84    RUN                         68.69    RUN
TW:C=?                               TW:C=?
             19.Ø5    RUN                          4.97    RUN

INPUT SET 9                          INPUT SET 12
TA:C=?                               TA:C=?
              19.6    RUN                          -1.4    RUN
WA:M/S=?                             WA:M/S=?
              4.Ø2    RUN                          2.64    RUN
RH:DEC=?                             RH:DEC=?
             Ø.363    RUN                         Ø.680    RUN
HSX:J/M2/S=?                         HSX:J/M2/S=?
             35Ø.7    RUN                         166.6    RUN
S/SØ:DEC=?                           S/SØ:DEC=?
              Ø.79    RUN                          Ø.6Ø    RUN
Q:CMS=?                              Q:CMS=?
             61.71    RUN                         7Ø.Ø8    RUN
TW:C=?                               TW:C=?
             15.66    RUN                          1.75    RUN
```

Figure III.5. (concluded)

```
INPUT SET 13
TA:C=?
                  XEQ "TW"

X1=-3.060701449
X2=0.657219546
X3=0.311811490
X4=4.878393160
X5=0.007710607
X6=0.514031660
X7=-0.004231396
R= 0.9999
ST:C= 6.954
ST.X:C= 0.072
d:C= 0.049


INPUT SET
TA:C=?
                -3.0     RUN
WA:M/S=?
                2.50     RUN
RH:DEC=?
               0.718     RUN
HSX:J/M2/S=?
               184.8     RUN
S/S0:DEC=?
                0.58     RUN
Q:CMS=?
               68.01     RUN
TW EST.=0.69 C


INPUT SET
TA:C=?
                 0.9     RUN
WA:M/S=?
                2.95     RUN
RH:DEC=?
               0.590     RUN
HSX:J/M2/S=?
               243.4     RUN
S/S0:DEC=?
                0.64     RUN
Q:CMS=?
               76.21     RUN
TW EST.=3.21 C


INPUT SET
TA:C=?
                 5.1     RUN
WA:M/S=?
                3.75     RUN
RH:DEC=?
               0.475     RUN
HSX:J/M2/S=?
               325.7     RUN
S/S0:DEC=?
                0.64     RUN
Q:CMS=?
               83.41     RUN
TW EST.=6.27 C


INPUT SET
TA:C=?
                10.9     RUN
WA:M/S=?
                4.29     RUN
RH:DEC=?
               0.400     RUN
HSX:J/M2/S=?
               407.7     RUN
S/S0:DEC=?
                0.67     RUN
Q:CMS=?
              148.64     RUN
TW EST.=10.25 C


INPUT SET
TA:C=?
                16.8     RUN
WA:M/S=?
                4.29     RUN
RH:DEC=?
               0.363     RUN
HSX:J/M2/S=?
               464.2     RUN
S/S0:DEC=?
                0.71     RUN
Q:CMS=?
              284.75     RUN
TW EST.=13.83 C
```

Figure III.6. HP-41C standard regression output example.

```
INPUT SET
TA:C=?
                 21.8     RUN
WA:M/S=?
                 4.38     RUN
RH:DEC=?
                 Ø.295    RUN
HSX:J/M2/S=?
                 486.6    RUN
S/SØ:DEC=?
                 Ø.79     RUN
Q:CMS=?
                 279.81   RUN
TW EST.=17.Ø5 C
```

```
INPUT SET
TA:C=?
                 25.9     RUN
WA:M/S=?
                 4.16     RUN
RH:DEC=?
                 Ø.328    RUN
HSX:J/M2/S=?
                 473.5    RUN
S/SØ:DEC=?
                 Ø.78     RUN
Q:CMS=?
                 118.Ø5   RUN
TW EST.=2Ø.41 C
```

```
INPUT SET
TA:C=?
                 24.1     RUN
WA:M/S=?
                 4.Ø2     RUN
RH:DEC=?
                 Ø.345    RUN
HSX:J/M2/S=?
                 425.7    RUN
S/SØ:DEC=?
                 Ø.76     RUN
Q:CMS=?
                 71.84    RUN
TW EST.=19.Ø8 C
```

```
INPUT SET
TA:C=?
                 19.6     RUN
WA:M/S=?
                 4.Ø2     RUN
RH:DEC=?
                 Ø.363    RUN
HSX:J/M2/S=?
                 35Ø.7    RUN
S/SØ:DEC=?
                 Ø.79     RUN
Q:CMS=?
                 61.71    RUN
TW EST.=15.69 C
```

```
INPUT SET
TA:C=?
                 12.7     RUN
WA:M/S=?
                 3.53     RUN
RH:DEC=?
                 Ø.43Ø    RUN
HSX:J/M2/S=?
                 265.3    RUN
S/SØ:DEC=?
                 Ø.74     RUN
Q:CMS=?
                 67.71    RUN
TW EST.=1Ø.62 C
```

```
INPUT SET
TA:C=?
                 4.3      RUN
WA:M/S=?
                 2.95     RUN
RH:DEC=?
                 Ø.57Ø    RUN
HSX:J/M2/S=?
                 196.4    RUN
S/SØ:DEC=?
                 Ø.63     RUN
Q:CMS=?
                 68.69    RUN
TW EST.=5.Ø1 C
```

Figure III.6. (continued)

```
INPUT SET
TA:C=?
                           -1.4    RUN
WA:M/S=?
                           2.64    RUN
RH:DEC=?
                          Ø.68Ø    RUN
HSX:J/M2/S=?
                          166.6    RUN
S/SØ:DEC=?
                           Ø.6Ø    RUN
Q:CMS=?
                          7Ø.Ø8    RUN
TW EST.=1.46 C
```

Figure III.6. (concluded)

Transformed Regression Program

This program provides a physically-based regression model at a specified point in the stream network, using either known water temperatures or calculated values. The resulting regression model can be used to provide starting temperatures at exterior points in the network; i.e., at headwaters and point loads. The regression model also can be used at interior points where known water temperatures are available; i.e., at validation and calibration gages.

It must be emphasized that regression models only provide water temperature predictions for the same location as the measured or calculated water temperatures and only reflect conditions for the independent hydrologic and geometric variables. The heat transport model is necessary for longitudinal water temperature predictions and to reflect changed hydrologic and stream geometry conditions. However, this particular regression model does provide estimates of key physical process parameters, x_o and t_o, that can be used in the heat transport program.

The transformed regression model uses a similar input data set as the heat transport program because the transformation is based on the heat transport model. However, some simplifications in the model were necessary, such as assuming constant discharge with no lateral flow.

The input requirements include stream geometry data for the specified point plus a minimum of six meteorological and corresponding hydrologic time period data sets.

The stream geometry data needed consist of representative parameters above the specified point. These parameters are: (1) stream elevation; (2) average stream width; (3) energy gradient (when using calculated water temperatures); and (4) starting source water temperatures and distance to the source. Stream geometry data are available from previous or current studies, field measurements, or quad sheets.

The meteorology data needed consist of station constants plus time period data. The station constants are the station elevation and mean annual air temperature. The time period data consist of time period averaged values for: (1) air temperature; (2) wind speed; (3) relative humidity; (4) extraterrestrial solar radiation; (5) solar altitude; (6) dust coefficient; (7) ground reflectivity coefficient; and (8) sunshine ratio. Meteorology data are available from published sources of weather data, the solar shade program, and the solar radiation program.

The hydrology data needed consist of average time period values for: (1) discharge; and (2) measured water temperatures when <u>not</u> using calculated water temperature data. Hydrology data are available from published sources, such as USGS records.

The transformed regression program prompts for all input. The first prompt determines whether known or calculated water temperature data will be used for the dependent variable.

The variable name list (in typical sequential order) is:

INPUT

Stream data

ZA ≡ representative stream elevation (meters above sea level)

B ≡ representative average stream width (m)

SH ≡ representative stream shade factor (decimal)

F ≡ representative stream gradient (m/m)

TO ≡ source water temperature (C)

O ≡ calculated distance to source (km)

State on constants

ZO ≡ station elevation (meters above sea level)

TY ≡ mean annual air temperature (C)

Average time period input data sets

TA ≡ air temperature (C)

WA ≡ wind speed (m/sec)

RH ≡ relative humidity (decimal)

HSX ≡ extra-terrestrial solar radiation ($J/m^2/sec$)

a ≡ solar altitude (radians)

d ≡ dust coefficient (decimal)

RG ≡ ground reflectivity coefficient (decimal)

S/SO ≡ sunshine ratio (decimal)

Q ≡ discharge (m^3/sec)

OUTPUT

TE ≡ transformed equilibrium water temperature (C)

K1 ≡ transformed first-order thermal exchange coefficient ($J/m^2/sec/C$)

TW ≡ calculated dependent variable water temperature (C)

X1 ≡ first regression coefficient

X2 ≡ second regression coefficient

X3 ≡ third regression coefficient

X4 ≡ fourth regression coefficient

X5 ≡ fifth regression coefficient

R ≡ coefficient of multiple correlation (decimal)

ST ≡ standard deviation of actual dependent variable data set (C)

ST.X ≡ standard deviation of the difference between the estimated and actual dependent variables for the original data set (C)

d ≡ probable error of estimate (C)

T_o ≡ regression model estimate of source temperature (C)

X0 ≡ regression model estimate of distance to source (km)

The procedure to use the transformed regression program is:

1. Clear the HP-41C.
2. Execute "SIZE 064".
3. Load the transformed regression program.
4. ASN "T R N R E G" Σ+.
5. ASN "C O R D A T" $\sqrt{x}$.
6. ASN "T W" LN.
7. Execute TRNREG by keying Σ+.
8. Input stream data.
9. Input station constants.
10. Input averaged time period input data sets.
11. Repeat step 10 until all data sets are entered.
12. Execute TW by keying LN.
13. Input independent variable data sets to determine TW.

If an incorrect data set is started, complete the operation and then execute CORDAT by keying $\sqrt{x}$ with an identical incorrect data set to recover. The program will automatically return to input the correct data set. Remember, the math pac is needed for this program.

Example. A regression model is needed to determine water temperatures at the mouth of an ungaged tributary. The hydrologist has used rainfall-runoff models to ascertain the contributing discharge to the main stem. The source of the discharge appears to be ground water that is entering the stream at the mean annual air temperature. Quad sheets and field visitations have provided the stream geometry data. A local weather station has the necessary meteorology data and the dust and ground reflectivity values have been estimated from the tables in Part II of this paper.

The meteorology station constants and Columns 2, 3, 4, and 5 in Table III.1 were obtained from published sources of meteorology data. Minimum and maximum values of dust and ground reflectivity were estimated from Table III.1. The solar data were obtained from the solar radiation program. Discharges were obtained from the hydrologist's rainfall-runoff model. The stream data were obtained from the hydrologist as a result of field visits and quad sheet study.

A copy of the HP-41C printer tape shows the input sequence (Fig. III.7) and corresponding output (Fig. III.8). The resulting regression statistics are summarized as:

$$\hat{T}_w = x_1 - \{x_2[(K_1\bar{B})/(\rho c_p Q)]\} + \{x_3[T_e(K_1\bar{B})/(\rho c_p Q)]\}$$

$$+ \{x_4[(K_1\bar{B})/(\rho c_p Q)]^2\} - \{x_5[T_e(K_1\bar{B})/(\rho c_p Q)]^2\}$$

with $R = 0.9985$ (decimal)

$ST = 6.954$ (C)

$ST.X = 0.380$ (C)

$d = 0.256$ (C)

$T_o = 13.30$ (C)

$X_o = 225.16$ (km)

The above regression model is available for use in predicting tributary water temperatures at the mouth of streams.

```
                XEQ "TRNREG"
KNOWN TW?
R/S=YES
NO=NO
                         RUN

STRM. DATA
ZA:M=?
                1431.    RUN
B :M=?
               91.44     RUN
SH:DEC=?
                .001     RUN
SF:M/M=?
             .000301     RUN

STA. CONST.
Z0:M=?
                 1476    RUN
TY:C=?
                 11.5    RUN


INPUT SET 1
TA:C=?
                 -3.0    RUN
WA:M/S=?
                 2.50    RUN
RH:DEC=?
                0.718    RUN
HSX:J/M*M/S=?
                184.8    RUN
a:RAD=?
               0.3710    RUN
d:DEC=?
               0.1989    RUN
RG:DEC=?
               0.3843    RUN
S/S0:DE=?
                 0.58    RUN
Q:CMS=?
                68.01    RUN
TW:C=?
                 0.47    RUN

TE:C= -0.77
K1:J/M*M/S/C= 16.78


INPUT SET 2
TA:C=?
                  0.9    RUN
WA:M/S=?
                 2.95    RUN
RH:DEC=?
                0.590    RUN
HSX:J/M*M/S=?
                243.4    RUN
a:RAD=?
               0.4533    RUN
d:DEC=?
               0.1989    RUN
RG:DEC=?
               0.3976    RUN
S/S0:DE=?
                 0.64    RUN
Q:CMS=?
                76.21    RUN
TW:C=?
                 3.17    RUN

TE:C= 3.42
K1:J/M*M/S/C= 19.40


INPUT SET 3
TA:C=?
                  5.1    RUN
WA:M/S=?
                 3.75    RUN
RH:DEC=?
                0.475    RUN
HSX:J/M*M/S=?
                325.7    RUN
a:RAD=?
               0.5596    RUN
d:DEC=?
               0.1925    RUN
RG:DEC=?
               0.3981    RUN
S/S0:DE=?
                 0.64    RUN
Q:CMS=?
                83.41    RUN
TW:C=?
                 6.42    RUN

TE:C= -7.56
K1:J/M*M/S/C= 23.64
```

Figure III.7. HP-41C transformed regression input example.

```
INPUT SET 4
TA:C=?
                      1Ø.9      RUN
WA:M/S=?
                      4.29      RUN
RH:DEC=?
                     Ø.4ØØ      RUN
HSX:J/M*M/S=?
                     4Ø7.7      RUN
a:RAD=?
                    Ø.6517      RUN
d:DEC=?
                    Ø.1797      RUN
RG:DEC=?
                    Ø.3853      RUN
S/SØ:DE=?
                      Ø.67      RUN
Q:CMS=?
                    148.64      RUN
TW:C=?
                     1Ø.15      RUN

TE:C= 12.62
K1:J/M*M/S/C= 29.17
```

```
INPUT SET 5
TA:C=?
                      16.8      RUN
WA:M/S=?
                      4.29      RUN
RH:DEC=?
                     Ø.363      RUN
HSX:J/M*M/S=?
                     464.2      RUN
a:RAD=?
                    Ø.7ØØ5      RUN
d:DEC=?
                    Ø.1613      RUN
RG:DEC=?
                    Ø.3598      RUN
S/SØ:DE=?
                      Ø.71      RUN
Q:CMS=?
                    284.75      RUN
TW:C=?
                     13.77      RUN

TE:C= -17.4Ø
K1:J/M*M/S/C= 34.31
```

```
INPUT SET 6
TA:C=?
                      21.8      RUN
WA:M/S=?
                      4.38      RUN
RH:DEC=?
                     Ø.295      RUN
HSX:J/M*M/S=?
                     486.6      RUN
a:RAD=?
                    Ø.7146      RUN
d:DEC=?
                    Ø.1389      RUN
RG:DEC=?
                    Ø.3234      RUN
S/SØ:DE=?
                      Ø.79      RUN
Q:CMS=?
                    279.81      RUN
TW:C=?
                     17.11      RUN

TE:C= 2Ø.27
K1:J/M*M/S/C= 38.6Ø
```

```
INPUT SET 7
TA:C=?
                      25.9      RUN
WA:M/S=?
                      4.16      RUN
RH:DEC=?
                     Ø.328      RUN
HSX:J/M*M/S=?
                     473.5      RUN
a:RAD=?
                    Ø.7Ø86      RUN
d:DEC=?
                    Ø.1137      RUN
RG:DEC=?
                    Ø.2785      RUN
S/SØ:DE=?
                      Ø.78      RUN
Q:CMS=?
                    118.Ø5      RUN
TW:C=?
                     2Ø.5Ø      RUN

TE:C= 22.88
K1:J/M*M/S/C= 41.67
```

Figure III.7. (continued)

```
INPUT SET 8
TA:C=?
                    24.1     RUN
WA:M/S=?
                    4.Ø2     RUN
RH:DEC=?
                   Ø.345     RUN
HSX:J/M*M/S=?
                   425.7     RUN
a:RAD=?
                  Ø.6735     RUN
d:DEC=?
                  Ø.1128     RUN
RG:DEC=?
                  Ø.2274     RUN
S/SØ:DE=?
                    Ø.76     RUN
Q:CMS=?
                   71.84     RUN
TW:C=?
                   19.Ø5     RUN

TE:C= 21.15
K1:J/M*M/S/C= 38.26
```

```
INPUT SET 9
TA:C=?
                    19.6     RUN
WA:M/S=?
                    4.Ø2     RUN
RH:DEC=?
                   Ø.363     RUN
HSX:J/M*M/S=?
                   35Ø.7     RUN
a:RAD=?
                  Ø.5953     RUN
d:DEC=?
                  Ø.1381     RUN
RG:DEC=?
                  Ø.2248     RUN
S/SØ:DE=?
                    Ø.79     RUN
Q:CMS=?
                   61.71     RUN
TW:C=?
                   15.66     RUN

TE:C= 17.Ø9
K1:J/M*M/S/C= 32.89
```

```
INPUT SET 1Ø
TA:C=?
                    12.7     RUN
WA:M/S=?
                    3.53     RUN
RH:DEC=?
                   Ø.43Ø     RUN
HSX:J/M*M/S=?
                   265.3     RUN
a:RAD=?
                  Ø.4871     RUN
d:DEC=?
                  Ø.16Ø7     RUN
RG:DEC=?
                  Ø.2753     RUN
S/SØ:DE=?
                    Ø.74     RUN
Q:CMS=?
                   67.71     RUN
TW:C=?
                   1Ø.55     RUN

TE:C= 11.3Ø
K1:J/M*M/S/C= 25.65
```

```
INPUT SET 11
TA:C=?
                     4.3     RUN
WA:M/S=?
                    2.95     RUN
RH:DEC=?
                   Ø.57Ø     RUN
HSX:J/M*M/S=?
                   196.4     RUN
a:RAD=?
                  Ø.39ØØ     RUN
d:DEC=?
                  Ø.1791     RUN
RG:DEC=?
                  Ø.32Ø7     RUN
S/SØ:DE=?
                    Ø.63     RUN
Q:CMS=?
                   68.69     RUN
TW:C=?
                    4.97     RUN

TE:C= 4.32
K1:J/M*M/S/C= 19.82
```

Figure III.7. (continued)

```
INPUT SET 12
TA:C=?
                              -1.4    RUN
WA:M/S=?
                              2.64    RUN
RH:DEC=?
                             Ø.680    RUN
HSX:J/M*M/S=?
                             166.6    RUN
a:RAD=?
                            Ø.3449    RUN
d:DEC=?
                            Ø.1922    RUN
RG:DEC=?
                            Ø.3577    RUN
S/SØ:DE=?
                              Ø.6Ø    RUN
Q:CMS=?
                             7Ø.Ø8    RUN
TW:C=?
                              1.75    RUN

TE:C= -Ø.33
K1:J/M*M/S/C= 17.22


INPUT SET 13
TA:C=?
```

Figure III.7. (concluded)

```
XEQ "TW"

X1=13.3Ø36
X2=3543939.45Ø
X3=225159.2616
X4=2.4113E11
X5=1.4447E1Ø
R= Ø.9985
ST:C= 6.954
ST.X:C= Ø.38Ø
d:C= Ø.256

TØ:C= 13.3Ø
XØ:KM= 225.16

INPUT SET
TA:C=?
        -3.Ø    RUN
WA:M/S=?
        2.5Ø    RUN
RH:DEC=?
        Ø.718   RUN
HSX:J/M*M/S=?
        184.8   RUN
a:RAD=?
        Ø.371Ø  RUN
d:DEC=?
        Ø.1989  RUN
RG:DEC=?
        Ø.3843  RUN
S/SØ:DE=?
        Ø.58    RUN
Q:CMS=?
        68.Ø1   RUN

TE:C= -Ø.77
K1:J/M*M/S/C= 16.78
TW,X:C= Ø.59
TW,e:C= 3.41

INPUT SET
TA:C=?
        Ø.9     RUN
WA:M/S=?
        2.95    RUN
RH:DEC=?
        Ø.59Ø   RUN
HSX:J/M*M/S=?
        243.4   RUN
a:RAD=?
        Ø.4533  RUN
d:DEC=?
        Ø.1989  RUN
RG:DEC=?
        Ø.3976  RUN
S/SØ:DE=?
        Ø.64    RUN
Q:CMS=?
        76.21   RUN

TE:C= 3.42
K1:J/M*M/S/C= 19.4Ø
TW,X:C= 3.81
TW,e:C= 6.24
```

Figure III.8. HP-41C transformed regression output example.

```
INPUT SET
TA:C=?
                 5.1     RUN
WA:M/S=?
                 3.75    RUN
RH:DEC=?
                 Ø.475   RUN
HSX:J/M*M/S=?
                 325.7   RUN
a:RAD=?
                 Ø.5596  RUN
d:DEC=?
                 Ø.1925  RUN
RG:DEC=?
                 Ø.3981  RUN
S/SØ:DE=?
                 Ø.64    RUN
Q:CMS=?
                 83.41   RUN

TE:C= 7.56
K1:J/M*M/S/C= 23.64
TW,X:C= 7.56
TW,e:C= 8.98
```

```
INPUT SET
TA:C=?
                 1Ø.9    RUN
WA:M/S=?
                 4.29    RUN
RH:DEC=?
                 Ø.4ØØ   RUN
HSX:J/M*M/S=?
                 4Ø7.7   RUN
a:RAD=?
                 Ø.6517  RUN
d:DEC=?
                 Ø.1797  RUN
RG:DEC=?
                 Ø.3853  RUN
S/SØ:DE=?
                 Ø.67    RUN
Q:CMS=?
                 148.64  RUN

TE:C= 12.62
K1:J/M*M/S/C= 29.17
TW,X:C= 12.62
TW,e:C= 12.88
```

```
INPUT SET
TA:C=?
                 16.8    RUN
WA:M/S=?
                 4.29    RUN
RH:DEC=?
                 Ø.363   RUN
HSX:J/M*M/S=?
                 464.2   RUN
a:RAD=?
                 Ø.7ØØ5  RUN
d:DEC=?
                 Ø.1613  RUN
RG:DEC=?
                 Ø.3598  RUN
S/SØ:DE=?
                 Ø.71    RUN
Q:CMS=?
                 284.75  RUN

TE:C= 17.4Ø
K1:J/M*M/S/C= 34.31
TW,X:C= 14.22
TW,e:C= 15.14
```

```
INPUT SET
TA:C=?
                 21.8    RUN
WA:M/S=?
                 4.38    RUN
RH:DEC=?
                 Ø.295   RUN
HSX:J/M*M/S=?
                 486.6   RUN
a:RAD=?
                 Ø.7146  RUN
d:DEC=?
                 Ø.1389  RUN
RG:DEC=?
                 Ø.3234  RUN
S/SØ:DE=?
                 Ø.79    RUN
Q:CMS=?
                 279.81  RUN

TE:C= 2Ø.27
K1:J/M*M/S/C= 38.6Ø
TW,X:C= 15.91
TW,e:C= 16.74
```

Figure III.8. (continued)

```
INPUT SET
TA:C=?
                  25.9     RUN
WA:M/S=?
                  4.16     RUN
RH:DEC=?
                 Ø.328     RUN
HSX:J/M*M/S=?
                 473.5     RUN
a:RAD=?
                Ø.7086     RUN
d:DEC=?
                Ø.1137     RUN
RG:DEC=?
                Ø.2785     RUN
S/SØ:DE=?
                  Ø.78     RUN
Q:CMS=?
                118.Ø5     RUN

TE:C= 22.88
K1:J/M*M/S/C= 41.67
TW,X:C= 2Ø.38
TW,e:C= 21.19
```

```
INPUT SET
TA:C=?
                  19.6     RUN
WA:M/S=?
                  4.Ø2     RUN
RH:DEC=?
                 Ø.363     RUN
HSX:J/M*M/S=?
                 35Ø.7     RUN
a:RAD=?
                Ø.5953     RUN
d:DEC=?
                Ø.1381     RUN
RG:DEC=?
                Ø.2248     RUN
S/SØ:DE=?
                  Ø.79     RUN
Q:CMS=?
                 61.71     RUN

TE:C= 17.Ø9
K1:J/M*M/S/C= 32.89
TW,X:C= 16.Ø7
TW,e:C= 16.82
```

```
INPUT SET
TA:C=?
                  24.1     RUN
WA:M/S=?
                  4.Ø2     RUN
RH:DEC=?
                 Ø.345     RUN
HSX:J/M*M/S=?
                 425.7     RUN
a:RAD=?
                Ø.6735     RUN
d:DEC=?
                Ø.1128     RUN
RG:DEC=?
                Ø.2274     RUN
S/SØ:DE=?
                  Ø.76     RUN
Q:CMS=?
                 71.84     RUN

TE:C= 21.15
K1:J/M*M/S/C= 38.26
TW,X:C= 18.75
TW,e:C= 2Ø.58
```

```
INPUT SET
TA:C=?
                  12.7     RUN
WA:M/S=?
                  3.53     RUN
RH:DEC=?
                 Ø.43Ø     RUN
HSX:J/M*M/S=?
                 265.3     RUN
a:RAD=?
                Ø.4871     RUN
d:DEC=?
                Ø.16Ø7     RUN
RG:DE=?
                Ø.2753     RUN
S/SØ:DE=?
                  Ø.74     RUN
Q:CMS=?
                 67.71     RUN

TE:C= 11.3Ø
K1:J/M*M/S/C= 25.65
TW,X:C= 11.3Ø
TW,e:C= 11.61
```

Figure III.8. (continued)

```
INPUT SET
TA:C=?
                     4.3     RUN
WA:M/S=?
                    2.95     RUN
RH:DEC=?
                   ∅.57∅     RUN
HSX:J/M*M/S=?
                   196.4     RUN
a:RAD=?
                  ∅.39∅∅     RUN
d:DEC=?
                  ∅.1791     RUN
RG:DEC=?
                  ∅.3207     RUN
S/S∅:DE=?
                    ∅.63     RUN
Q:CMS=?
                   68.69     RUN

TE:C= 4.32
K1:J/M*M/S/C= 19.82
TW,X:C= 4.32
TW,e:C= 6.49


INPUT SET
TA:C=?
                    -1.4     RUN
WA:M/S=?
                    2.64     RUN
RH:DEC=?
                   ∅.68∅     RUN
HSX:J/M*M/S=?
                   166.6     RUN
a:RAD=?
                  ∅.3449     RUN
d:DEC=?
                  ∅.1922     RUN
RG:DEC=?
                  ∅.3577     RUN
S/S∅:DE=?
                    ∅.6∅     RUN
Q:CMS=?
                   7∅.∅8     RUN

TE:C= -∅.33
K1:J/M*M/S/C= 17.22
TW,X:C= ∅.96
TW,e:C= 3.73
```

Figure III.8. (concluded)

Heat Transport Program

This program predicts longitudinal water temperatures. It includes the: (1) adiabatic meteorological correction model; (2) heat flux model; (3) heat transport model; and (4) flow mixing model. It determines the physical environment surrounding the stream reach and calculates a heat energy balance as the water flows downstream. The sole purpose of this program is to predict the time period averaged mean daily water temperature and, if requested, diurnal fluctuations.

The input requirements fall into the three basic categories of meteorology, stream geometry, and hydrology. The meteorology data are given with respect to a meteorological station. The adiabatic correction model transposes the data to the respective reaches. The meteorological station data consist of the station constants, the four standard weather variables, and solar parameters. The station constants are the station elevation and mean annual air temperature. The four weather variables are the time period averaged: (1) air temperature; (2) wind speed; (3) relative humidity; and (4) sunshine ratio. The solar parameters are the time period averaged: (1) extra-terrestrial solar radiation; (2) mean daily solar altitude; (3) dust coefficient; (4) ground reflectivity coefficient; and (5) daylight duration if diurnal fluctuation information is requested.

The stream geometry data needed consist of reach representative values for: (1) elevation; (2) average stream width; (3) shade factor; (4) stream gradient; and (5) hydraulic retardence n-value, if diurnal fluctuation information is requested. The shade factor also needs to be a time period average.

The appropriate shade factor is dependent on how the extra-terrestrial solar radiation is determined. If the solar radiation value is developed as if over level terrain, this shade factor should include both topographic and riparian vegetation shade. If the solar radiation value is developed reflecting local topography, this shade factor should include only the riparian vegetation shade.

The hydrology data needed consist of: (1) the discharge at the upstream end of the reach; (2) the lateral flow; and (3) the water temperature for the upstream discharge. The upstream discharge may be zero or a positive value; no negative discharges are permitted. The lateral flow may be negative (losing stream), zero (constant discharge), or positive (gaining stream). Negative lateral flows lose water at the stream water temperature. Positive lateral flows are assumed to gain water at the mean annual air temperature for the reach.

Information for the four standard weather variables are obtained from published sources; information for the solar parameters are obtained from the solar components. Stream geometry data are obtained from field observations and/or quad sheet studies. Shade factors can be determined or supplemented using the solar shade program. The hydrology data must come from a hydrologic analysis which, in turn, can use either gage data, calculated data, or a combination of the two types of data. The initial water temperatures come from measured or published data, supplemented with ouput from regression models; a priori knowledge, such as reservoir operating schemes; or development procedures, such as those given in the transformed regression program example.

The heat transport program prompts for all input. The first prompt determines whether or not the diurnal fluctuations option will be used. The remaining input is grouped according to a hierarchy. The first grouping is the meteorology station data, which are maintained as a group throughout the entire execution. The second grouping is the stream geometry data, which are maintained for the current hydrology and requested water temperature calculations, but have to be re-entered if the meteorology data change. The third grouping is the discharge data, maintained only for specific downstream water temperature calculations. An unlimited combination of initial water temperatures and downstream distances can be requested without having to re-enter the above three groupings of input data.

The variable name list, in typical sequential order, is:

INPUT (time period averaged where appropriate)

Meteorology station data

ZO ≡ station elevation (meters above sea level)

TY ≡ mean annual air temperature (C)

TA ≡ air temperature (C)

WA ≡ wind speed (m/sec)

RH ≡ relative humidity (decimal)

HSX ≡ extra-terrestrial solar radiation ($J/m^2/sec$)

a ≡ mean daily solar altitude (radians)

d ≡ dust coefficient (decimal)

RG ≡ ground reflectivity coefficient (decimal)

S/SO ≡ sunshine ratio (decimal)

SO ≡ daylight duration (hours)

Stream data (representative of reach)

ZA ≡ stream elevation (meters above sea level)

B ≡ average stream width (m)

SH ≡ shade factor (decimal)

SF ≡ stream gradient (m/m)

N ≡ hydraulic retardence n-value

Discharge data

QO ≡ upstream discharge (m^3/sec)

QL ≡ lateral flow (m^3/sec/km)

TE ≡ equilibrium water temperature (C)

K1 ≡ first-order thermal exchange coefficient (J/m^2/sec/C)

Heat flux (for equilibrium conditions) (J/m^2/sec)

HA ≡ atmospheric

HC ≡ convection

HD ≡ conduction

HE ≡ evaporation

HF ≡ friction

HS ≡ solar

HV ≡ riparian vegetation

HW ≡ water

INPUT

TO ≡ starting or initial water temperature of upstream discharge (C)

X ≡ downstream distance (km)

Note: X can be expressed as a single value to the nearest meter (three decimal places) or as a loop to the nearest kilometer. The format for the loop is bbb.eeeii where:

bbb is the beginning distance

eee is the ending distance

ii is the incremental distance

OUTPUT

K2 ≡ second-order thermal exchange coefficient ($J/m^2/sec/C^2$)

X ≡ downstream location (km)

Q/B ≡ unit discharge ($m^3/sec/m$)

TW ≡ mean daily water temperature (C)

TX ≡ maximum daytime water temperature (C)

TN ≡ minimum nighttime water temperature (C)

The procedure to use the heat transport program is:

1. Clear the HP-41C.
2. Execute "SIZE 047".
3. Load the heat transport program.
4. ASN "WATRAN" Σ+.
5. ASN "M T R L G Y" 1/x.
6. ASN "S T R M" $\sqrt{x}$.
7. ASN "D S C H R G" LOG.
8. ASN "Q M I X" LN.
9. Execute WATRAN by keying Σ+.
10. Input MET. STA. DATA.
11. Input STREAM DATA; adiabatic correction will execute.
12. Input DISCHARGE DATA, heat flux model will execute and output data.
13. Input TO and X; transport model will execute and output TW, etc.
14. Repeat step 13 as needed for current input data set.
15. Execute DSCHRG by keying LOG and repeat steps 12 through 14 if meteorology and stream geometry remains constant but discharge changes.
16. Execute STRM by keying $\sqrt{x}$ and repeat steps 11 through 14 if meteorology remains constant but stream geometry changes.

17. Execute MTRLGY by keying Y^X and repeat steps 10 through 14 if meteorology changes.

NOTE: QMIX may be used at any time without disturbing the other registers.

When tributaries join the main stem or point loads are added to the stream, the QMIX model is used. The variable list is:

QB ≡ discharge of main stem above junction (m^3/sec)

TB ≡ water temperature of main stem above junction (C)

QT ≡ discharge of tributary above junction (m^3/sec)

TT ≡ water temperature of tributary above junction (C)

QJ ≡ discharge in main stem below junction (m^3/sec)

TJ ≡ water temperature in main stem below junction (C)

Example. A prior analysis was made on a river basin and all the necessary input and output data are available. However, after the report was completed, the owners of a large reservoir on the main stem wanted to change their operating schedule to improve the power generating efficiency. To do so requires releasing 50 cms at 12.0 C. There is a Colorado squawfish spawning habitat in the mainstem below a junction with a major tributary 100 km downstream. The biologists believe that the July mean daily water temperature has to be greater than 20 C to ensure satisfactory squawfish spawning. The normal July water temperature immediately below the junction needs to be determined. The tributary normally has a flow of 35 cms at 22 C in July. No lateral inflow occurs along the mainstem.

The normal July meteorological data, the mainstem stream geometry data, and the normal July hydrology data for both the mainstem and the major tributary were obtained from published sources and output of previous HP-41C programs. A copy of the HP-41C printer tape (Fig. III.9) shows the input/output sequence. The study shows that the resulting water temperature of 20.11 C will be adequate for squawfish spawning.

```
                 XEQ "WATRAN"
DIURNAL FLUCTUATIONS?
R/S=YES
NO=NO
NO                       RUN


MET. STA. DATA
ZØ:M=?
                  1476   RUN
TY:C=?
                  11.5   RUN
TA:C=?
                  25.9   RUN
WA:M/S=?
                  4.16   RUN
RH:D=?
                 Ø.328   RUN
HSX:J/M2/S=?
                 473.5   RUN
a:RAD=?
                Ø.7Ø86   RUN
d:D=?
                Ø.1137   RUN
RG:D=?
                Ø.2785   RUN
S/SØ:D=?
                  Ø.78   RUN

STREAM DATA
ZA:M=?
                  1431   RUN
B :M=?
                 91.44   RUN
SH:D=?
                Ø.3711   RUN
SF:M/M=?
               .ØØØ3Ø1   RUN

DISCHARGE DATA
QØ:CMS=?
                    5Ø   RUN
QL:CMS/KM=?
                     Ø   RUN
```

```
OUTPUT
TE =2Ø.63 C
K1 =38.13 J/M2/S/C

HEAT FLUX:J/M2/S
HA =221.27
HC =45.4Ø
HD =-14.58
HE =-2ØØ.62
HF =1.61
HS =193.Ø7
HV =156.16
HW =4Ø2.3Ø
HSG=329.4Ø

INPUT
TØ:C=?
                   12.ØØ   RUN
X:KM=?
                     1ØØ   RUN

OUTPUT
K2 =Ø.625 J/M2/S/C/C

X = 1ØØ.ØØ KM
Q/B=Ø.5468 CMS/M
TW =18.79


INPUT
TØ:C=?
                XEQ "QMIX"


QB:CMS=?
                      5Ø   RUN
TB:C=?
                   18.79   RUN
QT:CMS=?
                      35   RUN
TT:C=?
                   22.ØØ   RUN

QJ:CMS=85.ØØØ
TJ:C=2Ø.11
```

Figure III.9. HP-41C heat transport input/output example.

BASIC SOLUTION TECHNIQUE

The overall structure of the mainframe computer technique has been severely boiled down to handle very simple systems similar to the HP-34C and HP-41C versions. A brief description of what this program asks for and an example session are included here. A listing of the BASIC program code is included in Part IV.

1. <u>How many kilometers downstream do you want to look?</u> If you are interested in a 7-mile reach of stream, you would enter 11 kilometers. The model expects metric data. Metric conversion factors can be found in Part II of this paper.

   Note: For debugging purposes, you may enter a -1 at this point and compare answers with those given in lines 420 to 450 of the BASIC listing.

2. <u>What is the discharge at the upstream point in cubic meters per second?</u> If 2 cfs is coming out of a dam or entering the reach, convert this to metric and enter 0.06 cms.

3. <u>What is the initial temperature of the water in degrees Celsius?</u> This refers to the water coming out of the dam or entering the reach.

4. <u>What is the total flow at the downstream point at this flow?</u> In other words, what is the measured flow in the river 11 kilometers downstream when the flow entering the reach is 0.06 cms? The model assumes essentially constant lateral inflow. If there are "major" tributaries entering along the way, it may be necessary to break the reach up into segments.

5. <u>What temperature is the lateral inflow in degrees Celsius?</u> In almost all cases, this temperature would be for ground water, which is the same as the mean annual air temperature. Put a thermometer down a well to get a "for sure" reading on this.

6. <u>What is the air temperature in degrees Celsius?</u> This one is pretty straightforward. But you will need to choose whether to opt for extreme values or average values as you would get them from the Local Climatological Data (LCD).

7. <u>What is the relative humidity as a decimal fraction?</u> Same situation as No. 6 above. You should use "average" daily, not just 5 a.m., data.

8. <u>What is the wind speed in meters per second?</u> Wind speed is also subject to "extreme" interpretation. Wind speed, however, may be used as a calibration parameter. That is, wind speed may be varied within reasonable bounds to achieve the known downstream temperatures when validating the model.

9. What is the percent possible sunshine from your LCD as a decimal fraction? This should come straight from the LCD. It is not a very sensitive parameter, but should do more than it does in this simplified implementation.

10. How much solar radiation is penetrating the water in Joules/m^2/sec? For example, if you wanted to calculate solar radiation entering the water around the Republican River in Nebraska, you could refer to Cinquemani et al. (1978) and calculate as follows (KJ/m^2/day):

Month	North Platte	Grand Island	Goodland	Topeka	Average
November	8617.0	8381.0	9721.0	8757.0	8869
December	6869.0	6462.0	7884.0	6622.0	6959
January	7858.0	7505.0	8959.0	7728.0	8013
February	10876.0	10407.0	11981.0	10679.0	10986
March	15128.0	14359.0	16159.0	14264.0	14978

The model requires J/m^2/sec. So:

solar radiation in J/m^2/sec = 0.011574*KJ/m^2/day

For example,

the solar radiation average for December = 6959 KJ/m^2/day

0.011574*6959 = 80.54 J/m^2/sec

Assuming 90% of this amount enters the water,

the model wants .9*80.54 = 72.49 J/m^2/sec.

11. What percent shading of the stream is there, expressed as a decimal? This is poorly worded, but refers to how much of the radiation is blocked by vegetation, cliffs, billboards, etc. If 10% of the stream is in a shadow, enter 0.1.

12. How many hours of daylight are there? Straightforward. Adjust for time of year.

13. What is the Manning's N factor (suggested value = .035)? If you have had the PHABSIM course, you will recognize Manning's N. Any simulation work you have done to determine N values is probably sufficient. This is not a sensitive parameter, especially with an upstream dam, because it really only controls diurnal temperature fluctuation.

14. What is the elevation in meters of the upstream point? The downstream point? Just take this off a 7 1/2' quad.

15. What is the A term (A = width, if width is constant)? What is the B term (B = 0, if width is constant)? These values may be derived from the width-discharge relationship. Plotted on log-log paper with the width on the Y-axis and discharge on the X-axis, the relationship should approximate a straight line. The B term is the slope of the line. The width is a fairly significant factor. Average width may be used, but try to get an accurate measurement.

16. What is the ground temperature in degrees Celsius? We suggest mean annual air temperature. About the only variation expected would be in a geothermal area.

17. What is the streambed thermal gradient (suggest 1.65)? It is not sensitive. Use 1.65.

18. Enter 1 for dam at upstream, Ø for no dam. Straightforward.

You must answer every question. There are no defaults. After the last question (number 18 above), you will have a chance to enter a new upstream discharge. An entry of -1 will reinitialize and start over with question #1.

An example of what is printed on the terminal and typical user entry is shown below. User entry is underlined for clarity.

```
Start up (e.g., MBASIC TEMPMOD)

Sign-on  Messages

TEMPMOD VERSION 1.1

How many kilometers downstream do you want to look?                        11

What is the discharge at the upstream point in cubic meters per second?  Ø.Ø6

What is the initial temperature of the water in degrees Celsius?            5

What is the total flow at the downstream point at this flow?                2

What temperature is the lateral inflow in degrees Celsius?                 15

What is the air temperature in degrees Celsius?                           -1Ø

What is the relative humidity as a decimal fraction?                       .3

What is the windspeed in meters per second?                                 2

What is the percent possible sunshine from your LCD as a decimal fraction? .5
```

See the manual on this next one....

How much solar radiation is penetrating the water in Joules/sq.m./sec? 117.76

What percent shading of the stream is there expressed as a decimal? .1

How many hours of daylight are there? 1Ø.4

What is the Manning's N factor (suggest value = .Ø35)? .Ø35

What is the elevation in meters of the upstream point? 6ØØ

What is the elevation in meters of the downstream point? 58Ø

For the equation WIDTH = A * Q ** B:

What is the A term (A = width, if width is constant)? 2

What is the B term (B = Ø, if width is constant)? Ø

What is the ground temperature in degrees Celsius?

We suggest mean annual air temperature. 15

What is the streambed thermal gradient (suggest 1.65)? 1.65

Enter 1 for dam at upstream, Ø for no dam? 1

TE = -6.108938

TE = 3.701417

The maximum daily water temperature is 14.11877 degrees Celsius?

The average daily water temperature is 13.91743 degrees Celsius?

The minimum daily water temperature is 13.7161 degrees Celsius?

Enter a new upstream discharge?

FORTRAN 77 SOLUTION TECHNIQUE

The instream water temperature model is a series of FORTRAN 77 computer programs designed to provide generalized instream water temperature simulation capabilities. The computer model allows users to work with large stream networks, variable temporal simulation periods, and large historical and synthetic data bases. The model consists of seven individual packages of FORTRAN 77 code: (1) JBCNUD - updates the run control parameters that control input and output in the job control file; (2) STRGEM - adds any required meteorology nodes and combines study and hydrology nodes into one composite stream geometry file; (3) HYDROL - checks for missing hydrology data, fills in missing discharge data, identifies missing required water temperature data, and computes lateral flows to create the final hydrology file; (4) METROL - merges the meteorology data with the hydrology and stream geometry data; (5) REGTWO - performs any required water temperature regression analysis; (6) TRNSPT - calculates the longitudinal water temperatures; and (7) VSTATS - calculates validation statistics, if any validation or calibration data are available.

System defaults for numeric fields are generally triggered by blank fields. For example, known lateral inflow water temperatures are required by the heat transport model. If the user believes that the local mean annual air temperature is a reasonable approximation for lateral inflow temperature (usually a reasonable assumption for ground water), the input field may be left blank and the computer program will supply the local mean annual air temperature as a default value. This is true for each field; i.e., non-blank character fields are taken directly and only blank fields default. The general rule is--if the user wants to use program defaults, leave the field(s) blank.

Generally, but not always, global true-false queries must contain a "T" if true. Any other character, including an "F" or a blank, is interpreted as false. The general rule is--if the user means true, use a "T"; if false, use an "F". Do not leave blank global true-false queries in the job control file. Blank local true-false queries in the node fields are legitimate responses because they signal the program that there is no local command to override a corresponding global command.

Features Offered

This computer program includes many powerful and convenient features. The user can reconstruct historical water temperature information and predict possible future water temperatures under gaming conditions.

A summary of the more significant features of the program is as follows:

(1) the network analysis can be used for any stream order and complexity;

(2) historical data can be used to validate (and calibrate) conditions within a particular basin or synthetic data can be used to simulate the effects of potential changes within the same or other basins;

(3) solar radiation can be calibrated at ground level to match observed solar data, if desired;

(4) the uncertainty of observed meteorological parameters can be reduced by calibration to observed water temperature data, if desired;

(5) there are convenient default values, such as the lateral inflow at the local mean annual air temperature;

(6) initial water temperatures at small, ungaged headwater sources can be conveniently simulated;

(7) water temperature regression analysis options are included;

(8) standard, moist-air adiabatic air temperature lapse rate adjustments are available;

(9) a convenient linkage to predetermined reservoir release temperatures is available;

(10) several algorithms are available to simulate the temperature of return flows;

(11) the type and amount of data output is user-controlled, including spatial and temporal restrictions;

(12) missing discharge data at hydrology nodes are automatically filled with the mean time period discharge at the respective node; however, entire discharge data at a hydrology node are not generated.

The user can calibrate the model to historical hydrology data by modifying the input meteorology data. After the model is calibrated, the meteorology calibration parameters remain constant for runs of synthetic hydrology data for gaming purposes. These runs allow for faster execution time by bypassing the regression analysis and validation steps used for historical data.

Linkage to Other Models

The instream water temperature model can be used as a stand alone or a linked model. In either mode, the input data are in the form of input files that can be modified by the user. There are provisions in the input file formats to allow the user to link the model with existing hydrology models.

Capabilities and Limitations

The instream water temperature package simulates the average daily water temperature and diurnal fluctuations anywhere within the defined stream network. It is necessary that stream flows and meteorology be steady over the averaging time period.

The programs in the package have been designed to operate on limited memory computers; the computer program structure is built around file utilization. The internal program dimensional limitations are set with PARAMETER statements and can be easily changed to accommodate specific applications.

The total number of nodes defined by the network and the total number of simulation temporal periods is limited mostly by the mass storage capabilities of the computer system being used.

ORGANIZATION OF DATA

Data Requirements

The data required by the temperature model includes job control information, six required input data sets, and an optional seventh data set. The input data sets are: (1) stream geometry data; (2) time period information; (3) meteorology information; (4) study node information; (5) hydrology node information; (6) hydrology data at the hydrology nodes; and (7) shade data (optional). Data sources are listed in the preceeding portions of Part III.

The stream geometry data consist of a definition of the stream system network (mainstem and tributaries), including site location (distance upstream from some arbitrary downstream site), and the stream geometry, including latitudes, elevations, Manning's n-value, stream width, shading data, ground temperatures, and streambed thermal gradient. The time period data include time step information, dust and ground reflectivity parameters, and calibration factors by time period for air temperature and wind speed. The required meteorological data are air temperature, wind speed, relative humidity, and percent possible sunshine. Observed solar radiation at ground level is optional.

Study node information includes site location information for points where output predictions are desired. Hydrology node information includes site location information for points in the system where hydrology data are required. Hydrology information at the hydrology nodes includes discharge, stream temperature for certain node types, lateral inflow temperature, and upstream discharge at any internal reservoirs in the system.

Shade data are required if the stream shade model is to be used to calculate riparian and topographic shading of the stream. Shade data include site latitude, site azimuth (orientation), stream width, and the vegetative parameters, vegetation height, crown measurement, vegetation offset, and vegetation density.

In addition to these data sets, there is a master job control data set that defines the extent of the job run and output produced.

Stream System Network. The stream system network is defined by the proper ordering of "node types". A node is a system descriptor point that defines what process is to be simulated at that location within the network. Initially, a stream system skeleton network is defined by the following nodes:

H (Headwater) - The upstream boundaries of tributaries and the mainstem.

B (Branch) - The point on the mainstem upstream of a tributary confluence.

T (Terminal) - The last point of a tributary before joining with a mainstem.

J (Junction) - The point on the mainstem just below a tributary confluence.

S (Structure) - A point (reservoir) at a headwater or within the stream network which may have a discontinuity in discharge and will have a release temperature controlled or defined by the user.

E (End) - The network end point; i.e., the furthest downstream node.

The skeleton network is the minimum number of nodes needed to define the network and is done once at the beginning of a particular study. The system should be represented by a schematic diagram that identifies the locations of these nodes in relation to one another with stream distances increasing upstream from a common system endpoint (Fig. III.10). The mainstem and tributary headwaters are generally chosen to coincide with locations having historical flow and temperature data or are the actual headwater sources at the point of zero discharge.

Once a common skeleton network is defined, additional node types may be added to locate points where additional hydrology, stream geometry, and output request information is necessary.

Additional hydrology nodes that may be added include:

Q (Discharge) - A node within the network that is used to redefine the quantity of instream and lateral flows.

V (Validation) - A node where the temperature is known and can be compared to predicted temperatures.

K (Calibration) - A node where the temperature is known and will be used for updating the water temperature information.

D (Point diversion) - A node from which water is to be diverted.

P (Point load) - A node where a point load discharges into the river at a known temperature.

R (Return) - A node where diverted flow returns as a point discharge into the river.

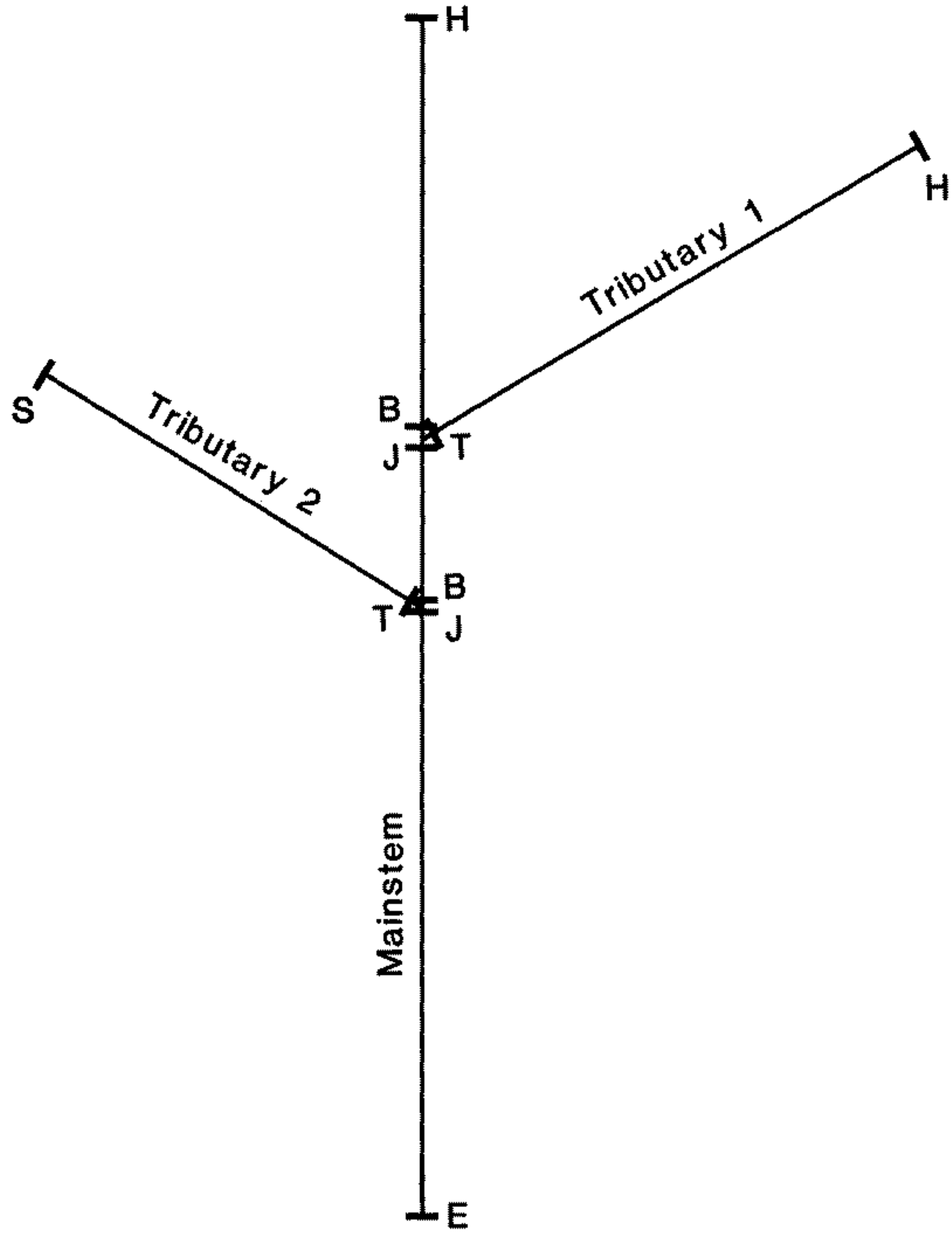

Figure III.10. Example schematic diagram that identifies the skeleton node locations.

Additional reach definitions and output nodes include:

C (Change) - The upstream end of a reach with new hydraulic or stream shading properties.

O (Output) - A node where output is desired.

When nodes are defined, they are assigned a 16-character stream name, a 1-character node type identifier, an 8-digit distance (km) relative to the system endpoint, and a 48-character remarks field describing the node. An example node is:

Green River	S	661.3	Flaming Gorge Dam

where the stream name is "Green River", node type is "S", distance is "661.3", and the remarks describe the node location as Flaming Gorge Dam.

Stream Geometry Data. After C nodes have been added to the stream skeleton network, the stream geometry nodes have been defined. The following data have to be supplied at all H, J, S, and C nodes to complete the resulting stream geometry data:

1. Site latitude (radians).
2. Site elevation (m).
3. Manning's *n*-value (dimensionless).
4. Stream width coefficient.
5. Stream width exponent.
6. Stream shading minimum (decimal).
7. Stream shading maximum (decimal).
8. Ground temperature (C).
9. Streambed thermal gradient ($J/m^2/sec/C$).

The first two variables (1 and 2) should be assigned the values that actually occur at the node location. The values of items 3 through 9 represent the average conditions between the current and next downstream stream geometry node.

The number of C nodes added to the skeleton network is dependent on the overall size of the network, the distance between skeleton nodes, and the uniformity of the system. It is recommended that a new C node be added whenever significant changes in physical stream geometry or shading occur. The model automatically supplies M nodes (meteorological) at every 300 m elevation change, if more than a 300 m difference in elevation exists between user-specified stream geometry nodes.

Variables 4 and 5 allow stream width to vary as a power function of the flow, i.e.;

width = (width coefficient) * flow ** (width exponent)

If a constant width is desired, the width exponent can be set to zero and the width coefficient set to the desired width.

Time Period. Time periods are groups of continuous days within each year that occur on a repeating cycle; e.g., months or weeks. Values for the following variables are required for all time steps to be simulated:

1. Time period name.
2. First day of the time period (Julian).
3. Last day of the time period (Julian).
4. Number of points for the time period average.
5. Dust coefficient (decimal).
6. Ground reflectivity (decimal).
7. Air temperature calibration constant.
8. Air temperature calibration coefficient.
9. Wind speed calibration constant.
10. Wind speed calibration coefficient.

The time period calibration factors (items 7 through 10) are used in the computer program to modify only the two indicated meteorological parameters, and does so for each associated time period according to the general form of:

$$\hat{y} = a_0 + a_1 y$$

where $\hat{y}$ ≡ the modified time period meteorological parameter

y ≡ the original input (or as modified previously by the global calibration factor) time period meteorological parameter

a_0 ≡ calibration constant factor for the indicated time period

a_1 ≡ calibration coefficient factor for the indicated time period

Global calibrations are made first and any subsequent time period calibrations are made afterwards. Blank or zeros in both factor fields (constant and coefficient) for each meteorological parameter defaults to no time period calibration for the indicated parameter and time period. A non-zero in either or both factor fields will result in a time period calibration for the indicated meteorological parameter and time period according to the above general form.

Meteorology. The instream water temperature model uses only one set of meteorological data. Thus data can be obtained from one meteorological station that is representative of the study area or can be synthesized from several stations into one data set.

Three time constant parameters that define the conditions of the meteorological data station are required:

1. The latitude of the station (radians).

2. The elevation of the station (m).

3. The average annual air temperature (C).

Values for the following variables are supplied for all years and time periods to be simulated:

1. Air temperature (C).

2. Wind speed (m/sec).

3. Humidity (decimal).

4. Sunshine ratio (decimal).

5. Measured solar radiation at ground level.

The first four variables are required for all years and time periods. Values for solar radiation are optional and, when supplied, only the values for the last time period entered are used.

Study Information. The study information data set consists of the skeleton network nodes plus any output (O) nodes at points where output is desired.

Hydrology Data. Flow data (cms) should be supplied for all simulation periods at all nodes in the skeleton network and at all hydrology (Q, D, P, R, V, and K) nodes. The flows at K, Q, and V nodes represent the flow within the channel at the respective node. Flows provided at P and R nodes represent the addition to the flow in the channel by the P or R node, respectively. The flow at a D node, always a positive number, is the amount of flow being diverted from the channel at this node.

Water temperatures (C) should be supplied for all years and time periods at all headwaters with a nonzero discharge. Point load discharge temperatures should be supplied for all years and time periods at point loads. Lateral discharge temperatures must be supplied at any point where the lateral inflow is not at local mean annual air temperature. If a validation and/or calibration is to be performed, water temperatures should be supplied at all V and/or

K nodes. If an occassional value for the historical water temperature is missing, the field shoud be left blank so that the regression model will supply an estimated temperature for that period.

Return flow water temperatures are controlled by the user. If the water temperature input field is blank, equilibrium water temperature is assumed. This simulates an overland flow condition. If the field is nonblank and nonzero, the value is assumed to be a ratio of lateral inflow and equilibrium water temperatures. If nonblank and negative, the absolute value is assumed to be the return flow water temperature. This last option is similar to a P node.

The temperature of water released from structures (reservoirs) must be provided (or options selected) for all simulation periods. Upstream inflow discharges to reservoirs must be provided for computation of lateral flows above the reservoir.

Job Control Variables. In addition to the actual data required by the system in order to perform simulations, information must be supplied that defines the size of the network, the extent of output desired, and other parameters. These variables are:

1. Requests for verification tables.
2. Network node types where output is desired.
3. Number of years of historical data.
4. Number of years of synthetic data.
5. First year of historical data, if all historical data is sequential without any gaps.
6. Maximum number of time periods.
7. Number of skeleton network nodes in the system.
8. Number of stream geometry network nodes.
9. Number of hydrology network nodes.
10. Number of study network nodes.
11. Total number of nodes in the system.
12. Number of nodes requiring regression analysis.
13. Number of nodes by individual node types.
14. Temporal output designations.
15. Evaporation coefficients.

16. Maximum daytime air temperature regression coefficients.

17. Global calibration factors.

18. Air temperature correction factors.

19. File names.

20. Spatial output requests by stream name with from/to distances.

The distance fields in item 20 are inclusive. If left blank or if zeroes are input in both fields, the from/to distances default to all nodes located in the network with that stream name.

Stream Identification. Each node has a unique identification distinct from every other node. The identification consists of a 16-character stream name; an 8-character node field, the first character of which is the node type identifier; and an 8-character data field containing the stream distance referenced from a common downstream point (usually the 'E' node). Distances always increase upstream. A 48-character remarks field is also allowed. While it is good practice to use the same remarks field when repeating the same node in different files, they do not have to be identical.

Remember, it takes all three fields (stream name, node type, and stream distance) to uniquely identify each node in the network. It is reasonable to have two nodes with the same stream name and distance, but different node types. For example, a Q node and a C node may occur at the same location.

Node Field. The node field (columns 17-24) consists of 6 useable characters (columns 23 and 24 are unused):

Character position	Must appear in file	Use
1	All files	Node type--part of stream identification.
2	Stream geometry	Local output flag--if this character is a "T", the corresponding node will appear in all output files regardless of other spatial output flag requests. If this character is an "F", the corresponding node will not appear in any output files regardless of other spatial output requests. Any other characters, including blanks, default to the global requests found in the job control file.
3	Hydrology node	Number of linkage records--integer numbers (0-9) used to indicate the number of hydrology linkage records that will immediately follow the current record in the hydrology node file. The linkage records are ignored by the program.
4	Hydrology node	Smooth/fill water temperature regression flag--default is fill, "S" is smooth, "F" is fill.
5	Hydrology node	Water temperature regression model option--default is "1": 1 - zero lateral heat transport. 2 - linear standard 2nd degree multiple regression. 3 - nonlinear complete heat transport; not currently available, will default to option "1". 4 - self initialization; for zero discharge sources. 5 - flow through, for release temperatures of reservoirs to be set equal to receiving temperatures. 6 - equilibrium release temperatures; for reservoirs where release discharges are skimmed from the surface and are assumed to be near equilibrium water temperature.
6	Stream geometry	Local shade model flag--overrides the global shade model flag if nonblank.
7 and 8		Unused

The first field column of the node field is always in column 17 of the stream identification record. While it is good practice to have the entire node fields identical for the same node in different files, it is not always necessary. However, those options pertaining to a specific file must appear in the node field as indicated above.

FILE STRUCTURE

The FORTRAN 77 computer program has a modular construction and was designed for vertical and horizontal portability; i.e., to be run on micro-, mini-, and large computer systems that support standard FORTRAN 77. Generated data are written to files rather than held internally in arrays. Three kinds of files are utilized: (1) input; (2) internal; and (3) output.

All input files are the responsibility of the user. They are formatted and sequential to allow easy access by system text editors. The program treats all input files, but the job control file, as read-only files.

Internal files are generated by the program and passed between modules. All internal files are binary; most are direct access. This design minimizes the internal I/O time. The module construction allows for procedural changes from the current genesis mode. The genesis mode is designed to create the original files. Internal files could be permanently saved to be used for purposes other than the genesis run. Procedures to do this are the responsibility of the user.

Output files are either formatted-sequential verification tables or the binary-sequential linkage file. More about both types follows.

Output Files

Nine formatted verification table files and one binary linkage file are available as output. The binary linkage file is automatically produced and is subject only to user-specified spatial and temporal restrictions. This binary file is designed to provide all the necessary parameters to easily generate water temperatures at or between any node within the network. It is intended to provide linkage to other computer programs for purposes of graphical displays, generating additional reports, or further analysis together with other water quality or quantity parameters.

The nine verification tables are designed to serve two purposes: (1) to provide the user with verification data as the program execution proceeds; and (2) to provide the user with final data that can be used directly in reports or presentations. These tables have been designed for compactness and readability to determine the correctness or reasonability of the calculations. However, processing large networks over large time spans can generate considerable output. The user will soon find that only certain key tables are likely to be routinely requested: for example, Table III because it contains all the node types within the entire network, including their corresponding stream geometry data; Table VI because it contains the meteorology, hydrology, and shade data at each user-specified node for the user-specified times; Table VII and IX because each contain important error-analysis statistics; and Table VIII because it contains the actual water temperature data at the user-specified nodes for each user-specified time. The other tables are useful if the user is concerned about specific calculations that may more easily be seen in that particular table.

The data in some tables are in space major - time minor order; i.e., the data are shown for all user-specified nodes for a given year and time period. In other tables, the data may be in time major - space minor order; i.e., all year and time period data for a given node are shown first. The stream geometry tables only have space dimensions since the geometry data are assumed to be constant over time.

The following descriptions of the verification tables are subject to the user-specified spatial and temporal restrictions. The tables are formatted for 133 column line printers with carriage control. The carriage control is either a "1" in column one for a new page or a blank otherwise.

Table I: Stream geometry after 'M' nodes merged. This table contains only the stream geometry nodes plus any required additional meteorology (M) nodes due to more than 300 m of elevation between adjacent nodes. The calculated average latitude, elevation, stream gradient, and streambed temperature between nodes are shown. The streambed (ground) temperature is assumed to be equal to the local mean annual air temperature. The streambed thermal gradient is shown and was assumed to be a constant of 1.65 $J/m^2/sec/C$. Certain other data, taken directly from the stream geometry file, are also shown. They are: (1) Manning's n-value; (3) stream width factors; and (3) min/max shade data. The min/max shade data at the respective node is used by the heat transport program only if the shade model is not, but the values are shown regardless. If Manning's n-value at the respective node is zero, then the diurnal fluctuation is not calculated at this node. And, if the stream width is a constant with respect to the flow, the stream exponent factor should be zero and the coefficient set equal to the width. Data are in space major order only since no temporal data are involved.

Table II: Stream geometry after '0' nodes merged. This table is identical to Table I, except the study file has been merged. Therefore, 0 nodes and their respective stream geometry data are added. The stream geometry data for 0 nodes are taken directly from the immediately preceeding upstream node. Data are in space major order only since no temporal data are involved.

Table III: Stream geometry after hydrology nodes merged. This table is identical to Table II, except the hydrology node file has been merged. Therefore, Q, D, K, R, and V nodes and their respective stream geometry data are added. The stream geometry data for these nodes are taken directly from the immediately preceeding upstream node. Data are in space major order only since no temporal data are involved.

Table IV: Hydrology with missing flows added. This table contains: (1) messages to the user concerning missing, but necessary, flow and water temperature data; and (2) discharge and water temperature data for each user-specified node over the user-specified times. Missing flows at all hydrology nodes, except the upstream flows for reservoirs, are filled-in with a calculated time period mean. Missing upstream flows for reservoirs are not permitted by the program except when using the flow-thru option and, therefore, are fatal program errors. Missing values for the required known stream-flow water temperatures (or the 'smooth' option) are flagged to be filled in later by the water temperature regression model(s). Missing lateral inflow water temperatures are filled with the local mean annual air temperature--the most likely situation, except in areas of geothermal activity. The table shows, at each user-specified node and for the user-specified times, the flow at the node and its water temperature where appropriate, the lateral inflow water temperature, and flow statistics over the entire historical years. D, P, and R node flows shown in the table are the flow additions at the node, not the flow in the stream. Data are presented in time major - space minor order.

Table V: Hydrology with lateral flows added. This table is similar to Table IV, but reverses the space-time order and adds lateral flow calculations. The table shows the flow at each node, the lateral flow downstream from the node, and any known water temperatures where appropriate. D, P, and R nodes are handled the same as in Table IV. Data are presented in space major - time minor order.

Table VI: Composite network--stream geometry, hydrology, and meteorology added. This table shows solar, shade, meteorological, and hydrology data for all the nodes in the entire network. Also shown is any solar calibration ratios. The shade data are the actual values that will be used by the heat transport model. The non-hydrology nodes are shown with the calculated flows based upon the immediately proceeding upstream hydrology node flow and lateral flow. The meteorology has been adjusted for lapse rate and any calibration options. This is the data used by the heat transport program. All data are in space major - time minor order.

Table VII: Water temperature regression statistics. This table shows the water temperature regression statistics. Mean, standard deviation, and the number of data points are given for the observed data. The correlation coefficient, probable error, maximum error, and bias error are shown for the comparison between the observed and regression predicted values. Physical interpretations are given where appropriate.

Table VIII: Water temperature data. This table shows the calculated (and observed where appropriate) daily and maximum water temperatures and certain other useful parameters for predicting water temperatures at each node in space major-time minor order. Data are presented in space major - time minor order.

Table IX: Validation statistics. This table gives the validation statistics at the validation and calibration nodes. Coefficient of determination, correlation coefficient, mean error, probable error, maximum error, and bias error are shown for the comparison between the observed water temperatures and heat transport model predicted values.

Input Files

At least seven input files are required by the instream water temperature model package. If the shade model is to be used, an additional input file is required, for a total of eight. The input data files can be created using a text editor. All input files, except the job control file, are treated as read-only files once they are constructed. All file formats are based on single or multiple fields of eight characters. All numeric data is entered as real numbers.

The programs of the temperature model make file data checks based on character position. It is very important that stream descriptors carried from one file to another are identical. Spelling errors, character position differences (blanks count as characters), or other differences cause an error during execution of the model.

The file names, except the job control file, are written in the job control file. This facilitates keeping track of all data associated with a particular temperature study. All input files have title lines for the user's convenience in identifying the file.

The eight input files used during execution of the model are: (1) job control file; (2) time period file; (3) meteorology file; (4) stream geometry file; (5) study file; (6) hydrology node file; (7) hydrology data file; and (8) (optional) shade file.

Output and shade model linkage are contolled by the job control file and by the node field of the stream indentification line in the stream geometry file. The job control file can be set to require the program to:

1. Include all or any combination of node types within the entire stream network in any requsted output file;

2. Include all nodes within user-specified streams or stream reaches by stream name and from/to distances;

3. Restrict output (and internal calculations) to user-specified years and time periods; and

4. Produce any combination of nine formatted verification tables containing the above user-specified nodes and times.

The job control file can also be used to set certain global conditions such as:

1. Use of the shade model in lieu of the stream geometry min/max shade values; and

2. Global calibration of all or any combination of the meteorological parameters.

The localized output and shade model linkage flags in the node field of the stream geometry file produce output or shade model linkage at individual nodes in the stream network regardless of the global requests.

Job Control File. The job control file is the master file that controls the extent of the temperature model runs. The verification requests, output requests, years of data simulated, node counts, calibration factors, file names, and temporal and spatial output requests are in this file. The job control file is the first file used by the temperature model programs, and the only input file that the program updates during execution of the model.

The first two records of the job control file are title lines. The format for the job control file is described in Table III.2.

Table III.2. Job control file format.

Record no.	Field	Variable description
1	1 - 80	Title line
2	1 - 80	Subtitle line
- - - - -	Verification Tables: field should contain a "T" if requested, an "F" otherwise -	
3	1	Tables I through IX
3	2	Tables I, II, and III
3	3	Table I: Stream geometry after M nodes merged
3	4	Table II: Stream geometry after O nodes merged

Table III.2. (continued)

Record no.	Field	Variable description
3	5	Table III: Stream geometry after hydrology nodes merged
3	6	Tables IV and V
3	7	Tables IV: Hydrology with missing flows added
3	8	Tables V: Hydrology with lateral flows added
3	9	Tables VI: Composite network - stream geometry, hydrology, and meteorology added
3	10	Tables VII: Water temperature regression statistics
3	11	Table VIII: Water temperature data
3	12	Table IX: Validation statistics
3	13 - 20	Reserved for future use
3	21 - 55	unused
- - - - -	Spatial Output Requests by Node Type; field should contain a "T" if requested, an "F" otherwise - - - - - - - - - - - -	
3	56	All skeleton nodes
3	57	All hydrology nodes
3	58	All stream geometry nodes
3	59	All study nodes
3	60	The composite stream network
3	61	B nodes
3	62	C nodes
3	63	D nodes
3	64	E nodes
3	65	H nodes

Table III.2. (continued)

Record no.	Field	Variable description
3	66	J nodes
3	67	K nodes
3	68	M nodes
3	69	O nodes
3	70	P nodes
3	71	Q nodes
3	72	R nodes
3	73	S nodes
3	74	T nodes
3	75	V nodes
3	76	Unused flag
3	77	Hydrology warning message suppression flag
3	78 - 79	Global shade linkage flags
3	80	Regression need flag
- - - - -	General Numeric Information - - - - - - - - - - - - - - - - - -	
4	1 - 8	Number of years of historical data
4	9 - 16	Number of years of synthetic data
4	17 - 24	First year of historical data
4	25 - 32	Number of time periods per year
4	33 - 40	Number of skeleton nodes
4	41 - 48	Number of stream geometry nodes
4	49 - 56	Number of hydrology nodes
4	57 - 64	Number of study nodes

Table III.2. (continued)

Record no.	Field	Variable description
4	65 - 72	Total number of nodes in the system
4	73 - 80	Number of nodes requiring regression analysis
- - - - -	Node Count Information -	
5	1 - 8	Number of B nodes
5	9 - 16	Number of C nodes
5	17 - 24	Number of D nodes
5	25 - 32	Number of E nodes
5	33 - 40	Number of H nodes
5	41 - 48	Number of J nodes
5	49 - 56	Number of K nodes
5	57 - 64	Number of M nodes
5	65 - 72	Number of O nodes
5	73 - 80	Number of P nodes
6	1 - 8	Number of Q nodes
6	9 - 16	Number of R nodes
6	17 - 24	Number of S nodes
6	25 - 32	Number of T nodes
6	33 - 40	Number of V nodes
- - - - -	Time Period Output Sequence Numbers - - - - - - - - - - - - -	
6	41 - 48	Starting year sequence number of output
6	49 - 56	Last year sequence number of output
6	57 - 64	First time period sequence number of output
6	65 - 72	Last time period sequence number of output

Table III.2. (continued)

Record no.	Field	Variable description
6	73 - 80	Number of nodes in output tables
- - - - -	User-Supplied Parameters -	
7	1 - 8	User-supplied evaporation factor
7	9 - 16	User-supplied evaporation factor
7	17 - 24	User-supplied evaporation factor
7	25 - 32	User-supplied Bowen ratio
7	33 - 40	1st maximum daily air temperature regression coefficient
7	41 - 48	2nd maximum daily air temperature regression coefficient
7	49 - 56	3rd maximum daily air temperature regression coefficient
7	57 - 64	4th maximum daily air temperature regression coefficient
7	65 - 72	Starting time period sequence number for air temperature correction; blank (or zero) field defaults to first possible time period
7	73 - 80	Last time period sequence number for air temperature correction; blank (or zero) field defaults to last possible time period
- - - - -	Global Calibration Factors - - - - - - - - - - - - - - - - - - -	
8	1 - 8	Global air temperature calibration constant
8	9 - 16	Global air temperature calibration coefficient
8	17 - 24	Global wind speed calibration constant
8	25 - 32	Global wind speed calibration coefficient
8	33 - 40	Global humidity calibration constant
8	41 - 48	Global humidity calibration coefficient

Table III.2. (continued)

Record no.	Field	Variable description
8	49 - 56	Global sunshine calibration constant
8	57 - 64	Global sunshine calibration coefficient
8	65 - 72	Global solar calibration constant
8	73 - 80	Global solar calibration coefficient
- - - - -	Air Temperature Correction Factors - - - - - - - - - - - - - -	
9	1 - 8	1^{st} elevation
9	9 - 16	1^{st} factor
9	17 - 24	2^{nd} elevation
9	25 - 32	2^{nd} factor
9	33 - 40	3^{rd} elevation
9	41 - 48	3^{rd} factor
9	49 - 56	4^{th} elevation
9	57 - 64	4^{th} factor
9	65 - 72	5^{th} elevation
9	73 - 80	5^{th} factor
- - - - -	Input File Names -	
10	1 - 16	Time period
10	17 - 32	Meteorology
10	33 - 48	Skeleton
10	49 - 64	Stream geometry
10	65 - 80	Study
11	1 - 16	Hydrology node
11	17 - 32	Hydrology data

Table III.2. (concluded)

Record no.	Field	Variable description
11	17 - 32	Hydrology data
11	33 - 48	Shade
11	49 - 80	Blank
- - - - -	Spatial Output Request by Stream Name - - - - - - - - - - - - -	
12	1 - 16	Local stream name for output
12	17 - 24	Starting distance for output
12	25 - 32	Ending distance for output
12	33 - 80	Blank
13 → 21		Repeat of record 12 description

Global calibration factors are used in the computer program to modify meteorological parameters according to the general form of

$$\hat{y} = a_0 + a_1 y$$

where $\hat{y}$ ≡ the modified meteorological parameter

y ≡ the original input meteorological parameter

a_0 ≡ the calibration constant factor

a_1 ≡ the calibration coefficient factor

The modified air temperature and wind speed parameters may be further modified with respect to time periods (see time period file). Blank (or zero) fields for both factors (constant and coefficient) defaults to no calibration of the respective meteorological parameters. A non-zero in either field for a particular meteorological parameter will result in calibration for that particular parameter.

The air temperature correction factors are used as indicated by the starting and last time period sequence numbers (record 7, columns 65-72 and 73-80). When the user does not believe that the default adiabatic air temperature correction model is applicable (-2C per 1000 ft), these factors provide an alternative model. An example of a situation that requires such an alternative would be air temperature inversion situations. The computer program, when instructed, linearly interpolates between indicated elevations. The air temperature at the indicated elevations is calculated as equal to its associated factor times the air temperature at the meteorology station. Air temperature elevations less than the first and greater than the last are assumed to be equal to the first or last, respectively. All five sets and the starting and last time period sequence numbers must be initialized to correctly use this feature. Otherwise, all five sets and the starting and last time period sequence numbers must be set to zero to use the adiabatic air temperature correction model.

Time Period File. The time period file is used to define the time periods to be simulated during each year and to assign values to variables that vary only by time period and not yearly. The format of this file is presented in Table III.3.

Table III.3. Time period file format.

Record no.	Field	Variable description
1	1 - 80	Title line
2	1 - 8	Time period name
2	9 - 16	First day of simulation period (Julian)
2	17 - 24	Last day of simulation period (Julian)
2	25 - 32	Number of points in time period average
2	33 - 40	Dust coefficient for simulation period
2	41 - 48	Ground reflectivity for simulation period
- - - - -	Calibration Factors by Time Period - - - - - - - - - - - - - -	
2	49 - 56	Air temperature calibration constant
2	57 - 64	Air temperature calibration coefficient
2	65 - 72	Wind speed calibration constant

Table III.3. (concluded)

Record no.	Field	Variable description
2	73 - 80	Wind speed calibration coefficient
3 → total time periods		Repeat calibration factors (record 2) for each respective time period

Meteorology File. The first record of the meteorology file is the title. The second record defines the meteorological station constants: (1) latitude; (2) elevation; and (3) mean annual air temperature. The remaining records in the file contain year and time period names, air temperature, wind speed, relative humidity, sunshine ratio, and, as optional data, any solar radiation measured at ground level for each time period of each year to be simulated. The format of the file is defined in Table III.4.

Table III.4. Meteorology file format.

Record no.	Field	Variable description
1	1 - 80	Title line
- - - - -	Meteorological Station Constants - - - - - - - - - - - - - -	
2	1 - 16	Blank
2	17 - 24	Latitude (radians)
2	25 - 32	Elevation (m)
2	33 - 40	Average annual air temperature (C)
2	41 - 80	Remarks to describe station
- - - - -	Meteorological Time Period Data - - - - - - - - - - - - - - -	
3	1 - 8	Year (only needed for first time period of the year)
3	9 - 16	Time period name
3	17 - 24	Mean air temperature for the time period

Table III.4. (concluded)

Record no.	Field	Variable description
3	25 - 32	Mean wind speed for the time period (m/sec)
3	33 - 40	Relative humidity for the time period (decimal)
3	41 - 48	Percent sunshine for the time period (decimal)
3	49 - 56	Observed solar radiation at ground level ($J/m^2/sec$)
3	57 - 80	Blank
4 → total time periods		Repeat meteorological data (record 3) for each year and time period

Note: Only the recorded observed solar radiation value for the last time period encountered is used.

Stream Network Files. The remaining files define the stream network. These files are:

1. Stream geometry file;
2. Study file;
3. Hydrology node file;
4. Hydrology data file; and
5. Shade file (optional).

When these files are built with a text editor, it is recommended that a skeleton network file be built first. The skeleton network file should be copied twice and these files used to build the stream network files. The format of the skeleton file is given in Table III.5.

Table III.5. Skeleton network file format.

Record no.	Field	Variable description
1	1 - 80	Title
- - - - -	Stream Node Descriptor	- -
2	1 - 16	Stream name
2	17 - 24	Node type identifier
2	25 - 32	Distance from the system endpoint (km)
2	33 - 80	Remarks to describe node
3 → system endpoint		Repeat stream node descriptor (record 2) for each node

The following steps can be used to define the skeleton network:

1. Build a schematic diagram of the network.

2. Select a system endpoint (usually with a distance of 0.0).

3. Select the network's mainstem.

4. Initialize the file with a title line.

5. The first entry after the title should be a mainstem headwater or a reservoir structure on the mainstem.

6. Proceed downstream with a recursive TEST-FOR-STRUCTURES-AND-TRIBUTARIES until the end of the network.

7. Insert "E" node and end the file.

The recursive procedure to TEST-FOR-STRUCTURES-AND-TRIBUTARIES is:

1. Proceed downstream on the current mainstem (or tributary) until a structure (reservoir) or tributary is encountered.

   If a structure is encountered, insert a node point with a "S" node type.

If a tributary is encountered, then,

(1) Insert a B node on the current mainstem (or tributary) with the same distance as the tributary confluence.

(2) Insert a starting "H" or "S" node for the tributary.

(3) Repeat the sequence of:
TEST-FOR-STRUCTURES-AND-TRIBUTARIES
on the current tributary until the end of the tributary.

(4) At the end of the tributary, insert a "T" node with the confluence distance.

(5) Insert a "J" node for the previous mainstem or tributary and proceed downstream.

(6) Repeat this procedure until the system endpoint is reached.

After the skeleton network file is constructed, the remaining system network files can be constructed by adding the appropriate information to copies of the skeleton network file. The information for each file is:

1. Stream geometry file = skeleton network + C nodes + stream geometry data.

2. Study file = skeleton network + O nodes.

3. Hydrology node file = skeleton network + hydrology nodes (D, K, Q, P, R, and V).

4. Hydrology data file = hydrology node file with discharges and pertinent water temperatures for each time period of each year.

5. Shade file = only nodes of stream geometry file that required stream geometry data with shade data added. For example, B nodes would not be included in the shade file.

Stream Geometry File. The stream geometry file is used to define the stream geometry in the system. Each node in the system is defined by three records in the file. One record is a blank line used as a visual separator between nodes. The next line is the node description line, and the third line is the stream geometry data. The first two lines are required for the shade file also. After adding the C nodes to the skeleton network, the stream geometry file should be copied to make the shade file. The format of the stream geometry file is given in Table III.6.

Table III.6. Stream geometry file format.

Record no.	Field	Variable description
1	1 - 80	Title line
2	1 - 80	Blank
3	1 - 16	Stream name
3	17	Node type
3	18	Local output flag
3	19	Hydrology model linkage flag
3	20 - 21	Regression model instructions
3	22	Local shade model linkage
3	23 - 24	Unused
3	25 - 32	Distance (km) from system reference point
3	33 - 80	Remarks describing node (for user's benefit, not used in simulation)
4	1 - 8	Site latitude (radians)
4	9 - 16	Site elevation (m)
4	17 - 24	Manning's n-value for the reach
4	25 - 32	Stream width coefficient for the reach (m)
4	33 - 40	Stream width exponent
4	41 - 48	Minimum stream shading (decimal)
4	49 - 56	Maximum stream shading (decimal)
4	57 - 64	Ground temperature (C)
4	65 - 72	Streambed thermal gradient ($J/m^2/sec/C$)
4	73 - 80	Blank
5, 6, and 7 → E node		Repeat information similar to records 2-4 for next geometry node

Study File. This file contains all the skeleton nodes plus any specific points where output is required by the user. These points may coincide with other studies on the stream system but are not included in any of the stream features of geometry, hydrology, or shading. An O node is inserted at these points. The format for the study file is given in Table III.7.

Table III.7. Study file format.

Record no.	Field	Variable description
1	1 - 80	Title line
2	1 - 16	Stream name
2	17	Node type
2	18	Local output flag
2	19	Hydrology model linkage flag
2	20 - 21	Regression instructions
2	22	Local shade model linkage flag
2	23 - 24	Unused
2	25 - 32	Distance (km) from system endpoint
2	33 - 80	Remarks describing node
3 → E node		Repeat of record 2 description

Hydrology Node File. This file contains all skeleton nodes plus all nodes where additional hydrology data is required (D, K, P, Q, R, and V nodes). The node identifier field in this file carries the instruction codes for the regression model. The records in this file can contain information used to link the instream temperature model with a hydrology model. Up to nine linking records can follow each node record as specified in field 19. The format of the linking records may vary depending on the type of linkage being performed. If the temperature model is to be used in conjunction with a hydrology model, the linkage documentation must be checked prior to building the hydrology node file. The format of the hydrology node file is given in Table III.8.

Table III.8. Hydrology node file format.

Record no.	Field	Variable description
1	1 - 80	Title line
2	1 - 16	Stream name
2	17	Node type
2	18	Local output flag
2	19	Number of records that follow with hydrology linkage instructions (digit)
2	20 - 21	Regression model instructions
2	22	Local shade model linkage flag
2	23 - 24	Unused
2	25 - 32	Distance from system endpoint (km)
2	33 - 80	Remarks describing node
3 → E node		Repeat of record 2

The format for hydrology linkage instructions, if any, that would follow the associated hydrology node record (see record 2, column 19 above) is ignored by this program. These records are for the user's convenience to link with other hydrology computer programs.

Hydrology Data File. The hydrology data file is a copy of the hydrology node file with discharge and temperature information added. Hydrology data are added for all years and time periods at one node before moving to the next node (time major, space minor order). When the temperature model is used in conjunction with a hydrology model, the form of the year and time period name fields may be restricted so it is imperative to check the linkage documentation prior to building this file. The format for the hydrology data file is given in Table III.9.

Table III.9. Hydrology data file format.

Record no.	Field	Variable description
1	1 - 80	Title line
2	1 - 80	Blank
3	1 - 80	Hydrology node description line (identical to hydrology node file)
4	1 - 8	Year (first time period of the year only)
4	9 - 16	Time period name
4	17 - 24	Discharge for the time period (cms)
4	25 - 32	Water temperature of the discharge (C)
4	33 - 40	Lateral inflow temperature (C)
4	41 - 48	Upstream inflow at a reservoir (S node)
5 until maximum years and time periods		Repeat record 4 format for each year and time period

Note: for each node in the hydrology node file, repeat records 2 through the maximum number of years and time periods.

Shade File. The shade file contains the information required to run the shade model concurrently with the temperature model. The shade values produced by this model are used in computing the effect of riparian and topographic shade on water temperatures. This file is optional and is only required if the shade model is selected by the user during a run of the temperature model. The node points in this file are identical to the node points in the stream geometry file that actually required stream geometry data; i.e., B nodes are not included. The shade file format is described in Table III.10.

Table III.10. Shade file format.

Record no.	Field	Variable description
1	1 - 80	Title line

Table III.10. (concluded)

Record no.	Field	Variable description
2	1 - 80	Blank
3	1 - 16	Stream name
3	17	Node type
3	18	Local output flag
3	19	Hydrology model linkage flag
3	20 - 21	Regression model instructions
3	22	Local shade model linkage flag
3	23 - 24	Unused
3	25 - 32	Distance from system endpoint (km)
3	33 - 80	Remarks describing node
4	1 - 8	Site latitude (radians)
4	9 - 16	Stream reach azimuth (radians)
4	17 - 24	Stream width (m)
4	25 - 80	Blank
5	1 - 8	Eastside topographic altitude (radians)
5	9 - 16	Eastside vegetation height (m)
5	17 - 24	Eastside vegetation crown measurement (m)
5	25 - 32	Eastside vegetation offset (m)
5	33 - 40	Eastside vegetation density (conifer); minimum density for deciduous trees
5	41 - 48	Eastside maximum density for deciduous trees; blank for conifers
6	1 - 80	Repeat of record 5 for westside parameters
For the remaining nodes		Repeat records 2 - 6

If a shade file is included, update the job control file flag line when completed. Record 3, column 78 of the job control file should be set to "T". This signals the program that shade data is available.

File Building Sequence

There is a hierarchy involved in building the input files for the temperature model. This hierarchy is based on the components of each file and the repetition, character for character, of information contained in one file to another. Figure III.11 is a representation of the file building hierarchy.

The job control file should be the first file created. This is the master control for the entire temperature model. This file will be updated with information from the other input files as they are constructed. The job control file should have all node counts and all run control parameters initialized before proceeding to the next file.

After the job control file is built, either the skeleton network file or the time period file can be constructed. Because the skeleton file provides the framework for several other files, the skeleton file may be constructed after the time period and meteorology files are created, but should be done prior to the others.

The time period file contains the time period names that will be duplicated in the meteorology file and data that vary by time period only, not yearly. Note that time periods cycle on a regular year-to-year basis. After the time period file is created, the maximum number of time periods per year should be written in the job control file. The meteorology file must have the time period names duplicated as they appear in the time period file. This sequence is repeated for every historical and synthetic year of data. The number of historical years, synthetic years, and the starting year, if appropriate, should be written to the job control file after the meteorology file is created.

The skeleton network file is constructed from a schematic representation of the system. All nodes in the skeleton network are repeated in the stream geometry, study, and hydrology node files. After the skeleton network file is created, it should be copied twice so that these three files can be built by inserting the appropriate nodes. All node counts should be written to the job control file after the files are constructed. The stream geometry, study, and hydrology node files can be constructed in any order after the skeleton network file.

The last two files that are constructed are the hydrology data and shade files. The shade file is a duplicate of all stream geometry data nodes in the stream geometry file and should be built after the stream geometry file. The hydrology data file is a copy of the hydrology node file with discharges and temperatures added.

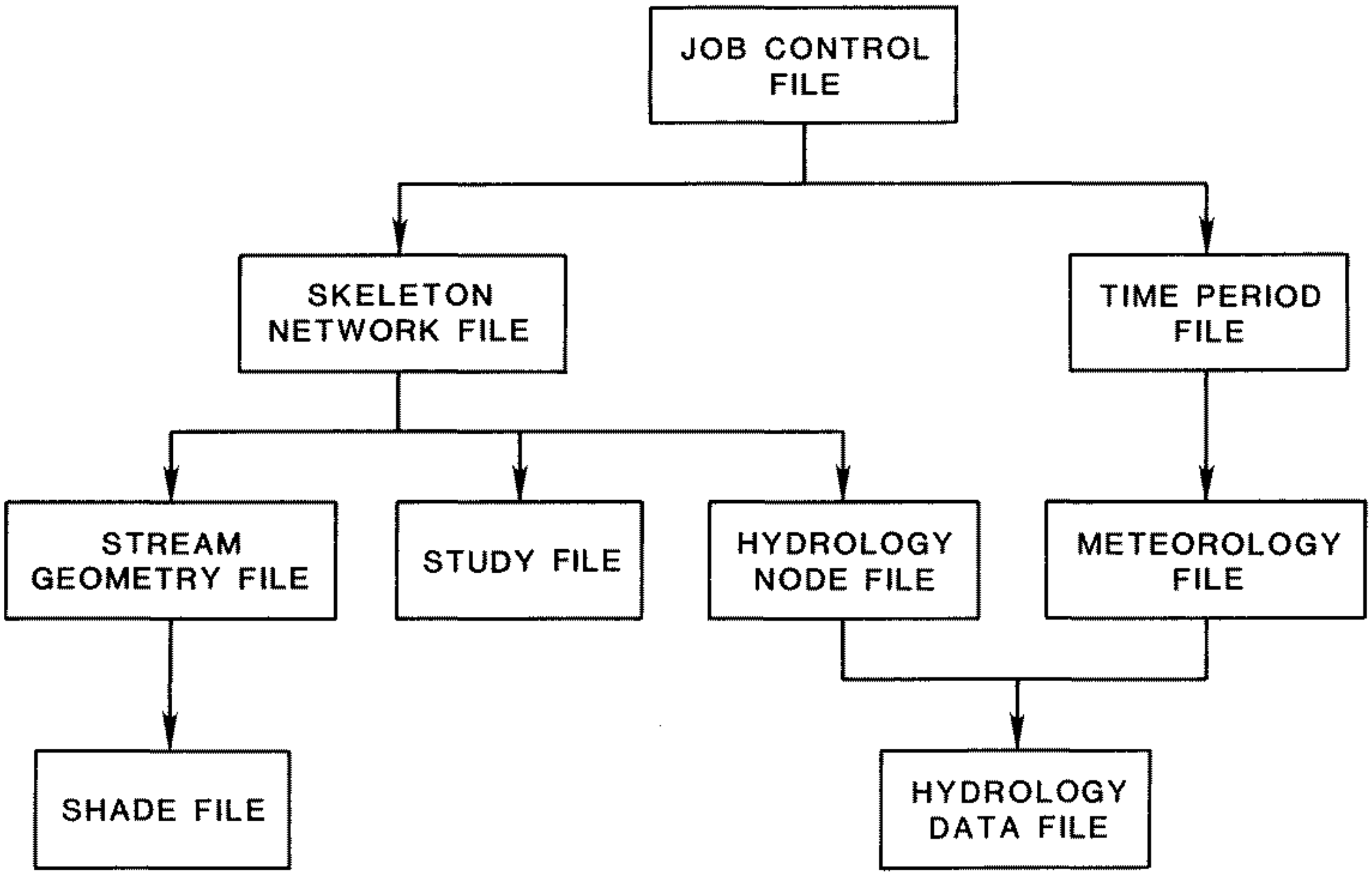

Figure III.11. Recommended file building sequence.

When all the input files are complete, the job control file should be updated with all node counts, number of years and time periods, run control parameters, file names, and any output requests by stream name and location. The output requests can be changed before each run of the model.

INTERNAL FILES

Internal files are binary files, usually direct access, that are passed between program components. As the user becomes more familiar with the program, different linkages will become apparent that will optimally serve purposes other than genesis runs. Part IV, Software Support Documentation, will give guidance.

EXAMPLE PROBLEM AND DATA ORGANIZATION

Example Description

The purpose of this section is to provide the user with a step by step example to follow when building the data files required for the temperature model. A detailed explanation of the data requirements and file structure was included in the previous sections of Part III.

The network example included below is the Upper Colorado River Basin subnetwork described in Part I, Applications, and shown in Figure I.1 as "Example 1 Subnetwork." The example files in this section include the seven required input files: (1) job control file; (2) time period file; (3) meteorology file; (4) stream geometry file; (5) study file; (6) hydrology node file; and (7) hydrology data file. In addition to these files, examples of a shade file and skeleton network file also are included.

Job Control File. The job control file is the master file that is used as a record keeping file for all the other files. It contains the node counts of all individual nodes, as well as the geometry, skeleton, study, and hydrology nodes. It also contains all the run control parameters for the temperature model. These parameters include output requests (spatial and temporal), number of years of data (historical and synthetic), calibration coefficients, and the input file names.

The job control file should be built first. Most of the data in the file are initialized to zero parameters in the original file. These zero variables are updated as the entire data set is completed. Table III.11 shows an example of the initial job control file. The first two lines of the file are title lines describing the file and the study. The third line is for verification tables and output requests. All fields are initialized to false and will be updated in the JBCNUD program.

Table III.11. Initial job control file.

```
JOB CONTROL FILE:  UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
TEMPERATURE MODEL COMPUTER PROGRAM VERIFICATION DATA SET
FFFFFFFFFFFFFFFFFFFF                                       FFFFFFFFFFFFFFFFFFFFFFFF
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.000
    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.000
    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.000
TIME PERIOD     METEOROLOGY     SKELETON        GEOMETRY        STUDY
HYDROLOGY NODE  HYDROLOGY DATA  SHADE
STR. NAME #1         0.0     0.0
STR. NAME #2         0.0     0.0
STR. NAME #3         0.0     0.0
STR. NAME #4         0.0     0.0
STR. NAME #5         0.0     0.0
STR. NAME #6         0.0     0.0
STR. NAME #7         0.0     0.0
STR. NAME #8         0.0     0.0
STR. NAME #9         0.0     0.0
STR. NAME #10        0.0     0.0
```

The remaining records in the file are initialized with variable values that will be updated before the initial run of the model. All node counts and calibration values are set to zero (lines 4 - 9). The file names are set to the descriptive names (lines 10 and 11), and the local spacial output requests are set to stream number and zero distances (lines 12 - 21). The only lines in the Job Control file that are not updated before the initial temperature model run are the title lines.

Time Period File. After the job control file is initialized, the next file created is the time period file. This file contains information that varies by simulation period during the year but not yearly. Table III.12 gives an example of the time period file. Line one is the title, which includes the phrase "TIME PERIOD FILE:". This quickly identifies the file for the user. The total number of records in the file depends on the number of simulation periods. Each line of the time period file contains the following variables: time period name; first day of the time period (Julian); last day of the time period (Julian); number of points used for the time period average; dust coefficient; ground reflectivity; and the four additional optimal variables, which are calibration factors for air temperature and wind speed. The calibration factors should be set to blanks (or zeros) for the initial run of the model.

Table III.12. Example time period file.

TIME PERIOD FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET					
OCT	274.	304.	2.	.16070	.33460
NOV	305.	334.	2.	.17910	.40450
DEC	335.	365.	2.	.19220	.25030
JAN	1.	31.	2.	.19890	.18990
FEB	32.	59.	2.	.19890	.25390
MARCH	60.	90.	2.	.19250	.37070
APRIL	91.	120.	2.	.17970	.29410
MAY	121.	151.	2.	.16130	.40250
JUNE	152.	181.	2.	.13890	.28120
JULY	182.	212.	2.	.11370	.16140
AUGUST	213.	243.	2.	.11280	.12690
SEPT	244.	273.	2.	.13810	.22690

Meteorology File. An example meteorology file is given in Table III.13. This file contains a title line with the phrase "METEOROLOGY FILE:" to help identify it. The second line contains the latitude, elevation, and mean annual air temperature for the meteorological station.

The remaining records contain the meteorological data occurring for each year and time period. The record for the first time period of the year contains the year, time period name, mean annual air temperature, mean wind speed, mean relative humidity, and percent possible sunshine. Any solar radiation measured at ground level is optional and goes after the percent sunshine. The remaining time periods for the year do not require the year in the first field.

All the time periods for all the years to be simulated are contained in the meteorology file. Notice, in the example, that the normal time periods contain values for solar radiation. Only the last values for solar radiation in the file are used to calibrate the solar model. If any values would have been in the file before the normals, they would have been replaced with the values in the normals during calibration of the solar model.

Skeleton Network. The example set has its headwaters at Flaming Gorge Dam on the Green River, the Maybell gage on the Yampa River, and the Lily gage on the Little Snake River. The network ends above the confluence of the Duschesne River on the Green River. Figure III.12 is the schematic diagram used to represent the system.

Table III.13. Example meteorology file.

METEOROLOGY FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET						
		.682715	1475.	11.5		
1959-60	OCT	11.33	3.62	.4250	.6800	
	NOV	3.39	3.26	.4800	.8900	
	DEC	0.11	3.04	.6675	.7000	
	JAN	-3.00	2.77	.7025	.6000	
	FEB	-1.44	3.40	.6200	.5800	
	MARCH	5.78	3.89	.5125	.7500	
	APRIL	11.72	4.65	.3200	.8400	
	MAY	16.33	4.65	.2800	.7300	
	JUNE	23.67	4.78	.2075	.9000	
	JULY	26.39	4.96	.2375	.9000	
	AUGUST	24.78	4.78	.2250	.9300	
	SEPT	20.67	4.60	.3500	.9000	
1960-61	OCT	12.22	4.11	.4550	.7800	
	NOV	5.28	3.62	.4650	.7300	
	DEC	-1.11	3.26	.6275	.8400	
	.	.	.	.	.	
	.	.	.	.	.	
	.	.	.	.	.	
	.	.	.	.	.	
	.	.	.	.	.	
1981-82	OCT	10.39	3.93	.6050	.6100	
	NOV	5.33	3.40	.6225	.6400	
	DEC	-0.39	2.91	.7325	.5100	
	JAN	-3.33	3.40	.7025	.5700	
	FEB	1.50	3.04	.6425	.6400	
	MARCH	7.78	4.34	.5300	.6500	
	APRIL	10.72	5.01	.3450	.8300	
	MAY	16.33	4.52	.4150	.7800	
	JUNE	22.33	5.19	.2775	.8800	
	JULY	26.11	4.16	.3275	.9300	
	AUGUST	25.67	3.89	.4675	.7800	
	SEPT	19.72	4.20	.5400	.6400	
NORMAL	OCT	12.72	3.53	.4450	.7300	176.7
	NOV	4.33	2.95	.5750	.6300	120.6
	DEC	-1.39	2.64	.6800	.6000	86.1
	JAN	-3.00	2.50	.7075	.5900	103.9
	FEB	.89	2.95	.5800	.6400	147.0
	MARCH	5.11	3.75	.4850	.6300	204.1
	APRIL	10.94	4.29	.3975	.6800	260.9
	MAY	16.78	4.29	.3700	.7100	312.6
	JUNE	21.83	4.38	.2950	.8000	342.4
	JULY	25.94	4.16	.3300	.7800	324.5
	AUGUST	24.11	4.02	.3550	.7600	286.6
	SEPT	19.56	4.02	.3750	.7900	241.0

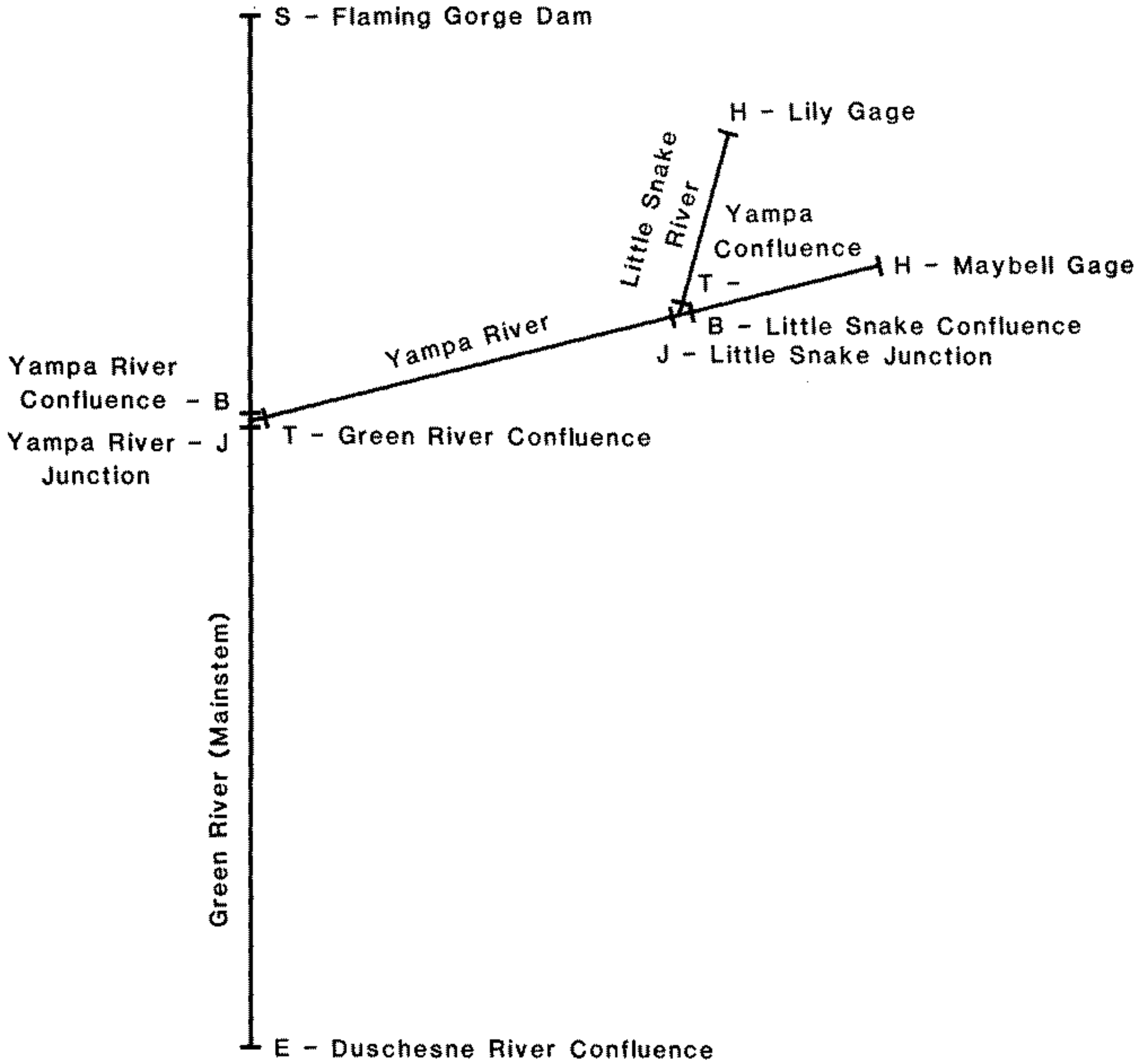

Figure III.12. Schematic diagram of the Upper Colorado River subnetwork.

The skeleton network developed from this diagram is shown in Table III.14. The skeleton starts at Flaming Gorge on the Green River. The first tributary branch is the Yampa River. Headwater for the Yampa River is the Maybell gage. A reservoir is simulated at Cross Mountain on the Yampa. The Little Snake River joins the Yampa. The Little Snake is modeled from the Lily gage down to the terminal point at the Yampa confluence. From the confluence with the Little Snake, the Yampa is modeled down to its terminus at the Green River. From the junction of the Yampa, the Green River is modeled to the system endpoint at the Duschesne River confluence.

Table III.14. Example skeleton file.

```
SKELETON FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
GREEN RIVER     S           661.3 FLAMING GORGE DAM
GREEN RIVER     B           556.7 YAMPA RIVER CONFLUENCE
YAMPA RIVER     H           681.5 MAYBELL
YAMPA RIVER     S           652.0 CROSS MOUNTAIN
YAMPA RIVER     B           638.8 LITTLE SNAKE CONFLUENCE
LITTLE SNAKE    H           651.6 LILY GAGE
LITTLE SNAKE    T           638.8 YAMPA CONFLUENCE
YAMPA RIVER     J           638.8 LITTLE SNAKE JUNCTION
YAMPA RIVER     T           556.7 GREEN RIVER CONFLUENCE
GREEN RIVER     J           556.7 YAMPA RIVER JUNCTION
GREEN RIVER     E           399.0 DUSCHESNE RIVER CONFLUENCE
```

This skeleton network is the basis for all the system network files. After creating the skeleton file, the file should be copied twice. These three copies of the skeleton file are used to make the stream geometry, study, and hydrology node files.

Stream Geometry File. The stream geometry file contains the physical dimensions of the system. The file (Table III.15) is created by adding C nodes to the skeleton network file. C (Change) nodes should be included wherever there is a change in any of the stream geometry parameters or in stream shading. For the example network, nine C nodes were defined.

Table III.15. Example stream geometry file.

```
STREAM GEOMETRY FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET

GREEN RIVER     S           661.3 FLAMING GORGE DAM
  .71413   1707.     .030   60.96    0.00  0.0001  0.0564

GREEN RIVER     C           617.9 LITTLE BROWN PARK
  .71326   1636.     .030   91.44    0.00  0.0022  0.0089

GREEN RIVER     C           580.8 LADORE CANYON
  .71035   1625.     .030   45.72    0.00  0.0962  0.2014
```

Table III.15. (concluded)

GREEN RIVER C			566.4 HELLS HALF MILE				
.71035	1565.	.030	60.96	0.00	0.1591	0.3004	
GREEN RIVER B			556.7 YAMPA RIVER CONFLUENCE				
.70744	1544.						
YAMPA RIVER H			681.5 MAYBELL				
.70686	1805.	.030	76.20	0.00	0.0000	0.0004	
YAMPA RIVER S			652.0 CROSS MOUNTAIN				
.70686	1805.	.030	76.20	0.00	0.0000	0.0004	
YAMPA RIVER B			638.8 LITTLE SNAKE CONFLUENCE				
.70715	1709.						
LITTLE SNAKE H			651.6 LILY GAGE				
.70744	1720.	.030	38.10	0.00	0.0019	0.0066	
LITTLE SNAKE T			638.8 YAMPA CONFLUENCE				
.70715	1709.						
YAMPA RIVER J			638.8 LITTLE SNAKE JUNCTION				
.70715	1709.	.030	45.72	0.00	0.0001	0.0019	
YAMPA RIVER C			627.5 LILY PARK				
.70744	1702.	.030	45.72	0.00	0.0000	0.0498	
YAMPA RIVER C			585.7 HARDING HOLE				
.70744	1575.	.030	45.72	0.00	0.0000	0.7673	
YAMPA RIVER T			556.7 GREEN RIVER CONFLUENCE				
.70744	1544.						
GREEN RIVER J			556.7 YAMPA RIVER JUNCTION				
.70744	1544.	.030	76.20	0.00	0.0000	0.6363	
GREEN RIVER C			537.4 ISLAND PARK				
.70686	1509.	.030	121.92	0.00	0.0036	0.0141	
GREEN RIVER C			526.1 RAINBOW PARK				
.70686	1503.	.030	60.96	0.00	0.0036	0.0141	
GREEN RIVER C			510.1 SPLIT MOUNTAIN				
.70628	1454.	.030	76.20	0.00	0.0544	0.1811	
GREEN RIVER C			502.0 FLATLAND BELOW SPLIT MOUNTAIN				
.70570	1446.	.030	91.44	0.00	0.0004	0.0018	
GREEN RIVER E			399.0 DUSCHESNE RIVER CONFLUENCE				
.69988	1415.						

The stream geometry file can be created by adding all the required geometry information and change nodes in one pass through the file, or it can be a two pass sequence, with the C nodes added on the first pass and the geometry information added on the second pass. The two pass sequence is recommended if the shade model will be used. After the C nodes are added in the first pass, a copy of the file is made to use in building the shade file. On the second pass through the geometry file, the geometry information is added.

At each H, J, S, and C node, the site latitude (radians), site elevation (m), Manning's n-value, stream width coefficient, stream width exponent, minimum shading, and maximum shading must be entered. If the ground temperature and stream bed thermal gradient are known to be significantly different from the default values, they are entered in the next two fields. The default values for these two parameters are the mean annual air temperature and 1.65 $J/m^2/sec/C$ as the streambed thermal gradient. The default values are recommended unless detailed information for these parameters has been collected. The default values are used in this example.

At B, T, and E nodes, only site latitude and elevation values are required. These are downstream-only points for the preceding stream reaches and are not part of the shade file. All other values for the stream reaches are average values supplied at the upstream node.

Study File. The study file is the skeleton network plus any O nodes at points where output is desired. The example network has one O node. These nodes coincide with sites of previous biological research on the river system. Table III.16 is the study file example.

Table III.16. Example study file.

```
STUDY FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
GREEN RIVER     S         661.3 FLAMING GORGE DAM
GREEN RIVER     B         556.7 YAMPA RIVER CONFLUENCE
YAMPA RIVER     H         681.5 MAYBELL
YAMPA RIVER     S         652.0 CROSS MOUNTAIN
YAMPA RIVER     B         638.8 LITTLE SNAKE CONFLUENCE
LITTLE SNAKE    H         651.6 LILY GAGE
LITTLE SNAKE    T         638.8 YAMPA CONFLUENCE
YAMPA RIVER     J         638.8 LITTLE SNAKE JUNCTION
YAMPA RIVER     T         556.7 GREEN RIVER CONFLUENCE
GREEN RIVER     J         556.7 YAMPA RIVER JUNCTION
GREEN RIVER     O         423.2 OURAY REFUGE STUDY SITE
GREEN RIVER     E         399.0 DUSCHESNE RIVER CONFLUENCE
```

Hydrology Node File. The hydrology node file is the skeleton network plus hydrology (D, K, P, Q, R, and V) nodes. Hydrology nodes are added at points where there is a change in point discharge or lateral flow rate or a point of known water temperature. The example network (Table III.17) has one V node added. There is one hydrology linkage record following each of the three headwater nodes and also one following the node at Flaming Gorge Dam. The data recorded on each record are the respective USGS gage numbers.

Table III.17. Example hydrology node file.

```
HYDROLOGY NODE FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
GREEN RIVER     S 1S2      661.3 FAMING GORGE DAM
        09234500
GREEN RIVER     B          556.7 YAMPA RIVER CONFLUENCE
YAMPA RIVER     H 1        681.5 MAYBELL
        09251000
YAMPA RIVER     S   5      652.0 CROSS MOUNTAIN
YAMPA RIVER     B          638.8 LITTLE SNAKE CONFLUENCE
LITTLE SNAKE    H 1        651.6 LILY GAGE
        09260000
LITTLE SNAKE    T          638.8 YAMPA CONFLUENCE
YAMPA RIVER     J          638.8 LITTLE SNAKE JUNCTION
YAMPA RIVER     T          556.7 GREEN RIVER CONFLUENCE
GREEN RIVER     J          556.7 YAMPA RIVER JUNCTION
GREEN RIVER     V 1S       485.9 JENSEN GAGE
        09261000
GREEN RIVER     E          399.0 DUSCHESNE RIVER CONFLUENCE
```

Hydrology Data File. The hydrology data file is created by copying the hydrology node file and inserting the required hydrology information. Table III.18 depicts the hydrology data file for the example network. Water temperatures are required at all headwater type (H and S) nodes with a nonzero discharge or a sufficient number of temperatures to permit the regression model to fill in missing data. If the lateral inflow associated with a stream reach differs from ground temperature, such as with a warm spring, that lateral temperature must be supplied.

Table III.18. Example hydrology data file.

```
HYDROOLOGY DATA SETFILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET

GREEN RIVER       S 1S2      661.3 FLAMING GORGE DAM
 1959-60    OCT   31.170
            NOV   24.110
            DEC   17.180
             •      •
             •      •
             •      •
             •      •
             •      •
 NORMAL     OCT   51.570     9.20
            NOV   52.940     8.37
            DEC   57.040     6.86
            JAN   53.400     4.71
            FEB   54.800     3.83
          MARCH   47.660     3.86
```

Table III.18. (concluded)

	APRIL	54.130	4.96	
	MAY	58.660	6.18	
	JUNE	66.350	7.88	
	JULY	60.380	9.29	
	AUGUST	56.840	9.85	
	SEPT	51.930	9.83	
GREEN RIVER	B			556.7 YAMPA RIVER CONFLUENCE
1959-60	OCT	31.695		
	NOV	25.774		
	DEC	15.636		
	•	•		
	•	•		
	•	•		
	•	•		
	•	•		
	SEPT	61.710		
GREEN RIVER	E			399.0 DUSCHESNE RIVER CONFLUENCE
1959-60	OCT	57.816		
	NOV	49.834		
	DEC	26.297		
	•	•		
	•	•		
	•	•		
	•	•		
	•	•		
	SEP	61.740		

Shade File. The shade file is used in the temperature model when the global or any local shade flag is set to true. This file calculates the riparian and topographic shade for the stream network. For the example network, the shade nodes are from the stream geometry file. Table III.19 illustrates the shade file for the example network. Because the H, J, S, and C nodes are completely representative of the stream reach, these are the only nodes required in the shade file.

Table III.19. Example shade file.

```
SHADE FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET

GREEN RIVER     S          661.3 FLAMING GORGE DAM
   .7141 -1.0472   60.96
   .2443    0.00    0.00    0.00  0.0000
   .2443    0.00    0.00    0.00  0.0000
```

Table III.19. (continued)

GREEN RIVER	C		617.9 LITTLE BROWN PARK	
.7133	-.5236	91.44		
.0844	0.00	0.00	0.00	0.0000
.0844	0.00	0.00	0.00	0.0000
GREEN RIVER	C		580.8 LADORE CANYON	
.7104	.1745	45.72		
.4363	0.00	0.00	0.00	0.0000
.4189	0.00	0.00	0.00	0.0000
GREEN RIVER	C		566.4 HELLS HALF MILE	
.7104	.1745	60.96		
.5992	0.00	0.00	0.00	0.0000
.4800	0.00	0.00	0.00	0.0000
YAMPA RIVER	H		681.5 MAYBELL	
.7069	1.5708	76.20		
.0349	0.00	0.00	0.00	0.0000
.0349	0.00	0.00	0.00	0.0000
YAMPA RIVER	S		652.0 CROSS MOUNTAIN	
.7069	1.5708	76.20		
.0349	0.00	0.00	0.00	0.0000
.0349	0.00	0.00	0.00	0.0000
LITTLE SNAKE	H		651.6 LILY GAGE	
.7074	.3491	38.10		
.0698	0.00	0.00	0.00	0.0000
.0698	0.00	0.00	0.00	0.0000
YAMPA RIVER	J		638.8 LITTLE SNAKE JUNCTION	
.7072	1.5708	45.72		
.0698	0.00	0.00	0.00	0.0000
.0698	0.00	0.00	0.00	0.0000
YAMPA RIVER	C		627.5 LILY PARK	
.7074	1.5708	45.72		
.2705	0.00	0.00	0.00	0.0000
.2705	0.00	0.00	0.00	0.0000
YAMPA RIVER	C		585.7 HARDING HOLE	
.7074	1.5708	45.72		
.5411	0.00	0.00	0.00	0.0000
.5411	0.00	0.00	0.00	0.0000
GREEN RIVER	J		556.7 YAMPA RIVER JUNCTION	
.7074	1.5708	76.20		
.4887	0.00	0.00	0.00	0.0000
.4887	0.00	0.00	0.00	0.0000

Table III.19. (concluded)

GREEN RIVER	C		537.4	ISLAND PARK
.7069	.5236	121.92		
.1076	0.00	0.00	0.00	0.0000
.1076	0.00	0.00	0.00	0.0000
GREEN RIVER	C		526.1	RAINBOW PARK
.7069	.5236	60.96		
.1076	0.00	0.00	0.00	0.0000
.1076	0.00	0.00	0.00	0.0000
GREEN RIVER	C		510.1	SPLIT MOUNTAIN
.7063	.5236	76.20		
.3956	0.00	0.00	0.00	0.0000
.3956	0.00	0.00	0.00	0.0000
GREEN RIVER	C		520.0	FLATLAND BELOW SPLIT MOUNTAIN
.7057	.7854	91.44		
.0436	0.00	0.00	0.00	0.0000
.0436	0.00	0.00	0.00	0.0000

The data each node requires are site latitude, stream azimuth, stream width, topographic altitude, vegetation height, crown measurement, vegetation offset, and vegetation density. Data for topographic altitude and vegetation are entered for the east and west sides of the stream. For the example Shade file (Table III.19), the vegetation shading was negligable and all values for vegetation parameters were set to zero.

Job Control File Completion

When all the input files are created, the job control file should have all the input node counts and parameters updated. Table III.20 shows the completed job control file for the example network. Compare the completed file with the initial file, Table III.11, to see the difference.

Table III.20. Completed job control file.

```
JOB CONTROL FILE:  UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
TEMPERATURE MODEL COMPUTER PROGRAM VERIFICATION DATA SET
FFFFFFFFFFFFFFFFFFFF                                       FFFFFFFFFFFFFFFFFFFFFFFF
     23.        1.        0.       12.        0.       20.       12.       11.        0.        0.
      0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
      0.        0.        0.        0.        1.       24.       24.        1.       12.        0.
    0.00    0.0000      0.00    0.0000      0.00    0.0000      0.00    0.0000      0.00     0.000
    0.00    0.0000      0.00    0.0000      0.00    0.0000      0.00    0.0000      0.00     0.000
    0.00    0.0000      0.00    0.0000      0.00    0.0000      0.00    0.0000      0.00     0.000
KVRFTME         KVRFMET         KVRFSKL         KVRFSTR         KVRFSTD
KVRFHDR         KVRFHYD         KVRFSHD
YAMPA RIVER        556.7     681.5
GREEN RIVER        423.2     556.7
STR. NAME #3         0.0       0.0
STR. NAME #4         0.0       0.0
STR. NAME #5         0.0       0.0
STR. NAME #6         0.0       0.0
STR. NAME #7         0.0       0.0
STR. NAME #8         0.0       0.0
STR. NAME #9         0.0       0.0
STR. NAME #10        0.0       0.0
```

EXAMPLE PROGRAM EXECUTION

Program Overview

The program packages used in the instream water temperature model are: (1) JBCNUD - the job control update program; (2) STRGEM - the stream geometry program; (3) HYDROL - the hydrology program; (4) METROL - meteorology program; (5) REGTWO - regression program; (6) TRNSPT - heat transport program; and (7) VSTATS - validation statistics program. A discussion of these programs is in Part IV - SOFTWARE SUPPORT section of this manual. The model execution in this section is for model users and does not include detailed descriptions of the program coding.

The model is designed to be transferrable to any computer system that supports FORTRAN 77 and can be executed as batch or from a CRT-type terminal as an interactive job. Therefore, each user must set up their own system procedures to execute the program. The model was developed on a CDC CYBER mainframe, and the following example is from that system. The following run of the model used the Upper Colorado River Basin example data set.

JBCNUD - Job Control Update Program. The JBCNUD program is the first program executed during a run of the model. To run this program, the job control file, time period file, meteorology file, and executable version of JBCNUD must be in local working space.

The job control update program is the only portion of the model that requires interactive input. Start JBCNUD with the system command required to run a FORTRAN program. The first prompt is for the job control file name. In these examples, the user's responses are lower case.

JBCNUD update example

```
>>>>>>>>>>>>>>>>>>>>>>>>> ENTERING 'JBCNUD' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<
 WHAT IS THE JOB CONTROL FILE NAME?
? kvrfjob
JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
TEMPERATURE MODEL COMPUTER PROGRAM VERIFICATION DATA SET
```

After the job control file name is entered, the title lines are printed at the terminal and the update begins. The first update is for verification tables. If this is the first run for a data set, all verification tables should be requested. The following example came from the initial run of the example data set.

Verification table example

```
 DO YOU WANT TO CHANGE THE VERIFICATION TABLE REQUESTS?
  'Y' OR 'N'
? y

 THE FOLLOWING VERIFICATION TABLE REQUESTS ARE AVAILABLE:
REQUEST NUMBER                TABLE NAME
          1         TABLES I-IX:   ALL VERIFICATION TABLES
          2         TABLES I-III:  ALL THREE STREAM GEOMETRY TABLES
          3         TABLE I:       STREAM GEOMETRY AFTER 'M' NODES MERGED
          4         TABLE II:      STREAM GEOMETRY AFTER 'O' NODES MERGED
          5         TABLE III:     STREAM GEOMETRY AFTER HYDROLOGY NODES MERGED
          6         TABLES IV-V:   BOTH HYDROLOGY TABLES
          7         TABLE IV:      HYDROLOGY WITH MISSING FLOWS ADDED
          8         TABLE V:       HYDROLOGY WITH LATERAL FLOWS ADDED
          9         TABLE VI:      COMPOSITE-STR. GEOM., HYDR., & MET. MERGED
         10         TABLE VII:     WATER TEMPERATURE REGRESSION STATISTICS
         11         TABLE VIII:    WATER TEMPERATURE DATA
         12         TABLE IX:      VALIDATION STATISTICS

 ENTER TABLE REQUEST NUMBER
 ENTER 'FINISH' OR -CR- TO TERMINATE
 REQUEST NUMBER = ?
? 1
 REQUEST NUMBER = ?
?
```

The user entered a "1", requesting all tables and, when prompted again, entered a carriage return to end the verification updates.

The next prompts are spatial designations for output. The user updates the output requests by entering the number of the request, followed by a carriage return. These are global requests that are produced for the entire system. The requests for spacial output by stream name in the job control file will include all the nodes in the designated reaches. In this example, the user entered a "5" and requested all global output.

Output request example

```
 DO YOU WANT TO CHANGE THE SPATIAL DESIGNATIONS OUTPUT REQUESTS?
  'Y' OR 'N'
? y

 THE FOLLOWING OUTPUT REQUESTS ARE AVAILABLE
REQUEST NUMBER                OUTPUT TYPE
          1        OUTPUT FOR ALL SKELETON NODES
          2        OUTPUT FOR ALL HYDROLOGY NODES
          3        OUTPUT FOR ALL STREAM GEOMETRY NODES
          4        OUTPUT FOR ALL STUDY NODES
          5        OUTPUT FOR THE COMPOSITE STREAM NETWORK
          6        OUTPUT ONLY AT 'B' NODES
          7        OUTPUT ONLY AT 'C' NODES
          8        OUTPUT ONLY AT 'D' NODES
          9        OUTPUT ONLY AT 'E' NODES
         10        OUTPUT ONLY AT 'H' NODES
         11        OUTPUT ONLY AT 'J' NODES
         12        OUTPUT ONLY AT 'K' NODES
         13        OUTPUT ONLY AT 'M' NODES
         14        OUTPUT ONLY AT 'O' NODES
         15        OUTPUT ONLY AT 'P' NODES
         16        OUTPUT ONLY AT 'Q' NODES
         17        OUTPUT ONLY AT 'R' NODES
         18        OUTPUT ONLY AT 'S' NODES
         19        OUTPUT ONLY AT 'T' NODES
         20        OUTPUT ONLY AT 'V' NODES
 ENTER OUTPUT REQUEST NUMBER
 ENTER 'FINISH' OR -CR- TO TERMINATE REQUESTS
REQUEST NUMBER = ?
? 5
 REQUEST NUMBER = ?
?
```

The next prompt is for changes in temporal output requests. The program prompts for changes by years and time period. The user enters the request numbers for the years and time periods available in the data set. In the following example, the user requested only the year "NORMAL" and all time periods.

Temporal output request example

```
 DO YOU WANT TO CHANGE THE TEMPORAL OUTPUT REQUEST DESIGNATIONS
  (YEARS AND/OR TIME PERIODS)?  'Y' OR 'N'
? y

 DO YOU WANT TO CHANGE YEAR OUTPUT REQUEST DESIGNATIONS
  'Y' OR 'N'
? y

 THE FOLLOWING OUTPUT REQUESTS ARE AVAILABLE

                     YEAR
                   REQUEST
                    NUMBER                YEAR

                      1                 1959-60
                      2                 1960-61
                      3                 1961-62
                      4                 1962-63
                      5                 1963-64
                      6                 1964-65
                      7                 1965-66
                      8                 1966-67
                      9                 1967-68
                     10                 1968-69
                     11                 1969-70
                     12                 1970-71
                     13                 1971-72
                     14                 1972-73
                     15                 1973-74
                     16                 1974-75
                     17                 1975-76
                     18                 1976-77
                     19                 1977-78
                     20                 1978-79
                     21                 1979-80
                     22                 1980-81
                     23                 1981-82
                     24                  NORMAL

  ENTER YOUR BEGINNING YEAR REQUEST NUMBER.
? 24
  ENTER YOUR ENDING REQUEST YEAR NUMBER.
? 24
                    YOUR YEAR OUTPUT REQUEST ARE

                    BEGINNING YEAR---  NORMAL
                       ENDING YEAR---  NORMAL

 DO YOU WANT TO CHANGE TIME PERIOD OUTPUT REQUEST DESIGNATIONS?
  'Y' OR 'N'
? y
```

Temporal output request example (concluded)

```
 THE FOLLOWING OUTPUT REQUESTS ARE AVAILABLE

                    TIME PERIOD
                     REQUEST
                      NUMBER                TIME PERIODS

                         1                       OCT
                         2                       NOV
                         3                       DEC
                         4                       JAN
                         5                       FEB
                         6                     MARCH
                         7                     APRIL
                         8                       MAY
                         9                      JUNE
                        10                      JULY
                        11                    AUGUST
                        12                      SEPT

  ENTER YOUR BEGINNING TIME PERIOD OUTPUT REQUEST NUMBER
? 1
  ENTER YOUR ENDING TIME PERIOD OUTPUT REQUEST NUMBER
? 12
                 YOUR TIME PERIOD OUTPUT REQUEST ARE

                     BEGINNING PERIOD---    OCT
                        ENDING PERIOD---   SEPT
```

The final prompt for the job control file is the global shade model linkage. If the user responds with a "yes", the data in the shade file will be used to calculate the shade values for the stream system. For the example set, the user selected not to use the shade model.

Shade model linkage example and JBCNUD completion message

```
 IS THE GLOBAL SHADE MODEL FLAG TO BE SET TO TRUE?
  'Y' OR 'N'
? n

 THE GLOBAL SHADE MODEL FLAG IS SET TO FALSE.

 THE FORMATTED (GENESIS) JOB CONTROL FILE HAS BEEN UPDATED.
 THE UNFORMATTED (BINARY) JOB CONTROL FILE HAS BEEN CREATED.
>>>>>>>>>>>>>>>>>>>>>>>>>> EXITING 'JBCNUD' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
```

The last message printed at the terminal before the end of the program tells the user that the job control file is updated and a binary job control file has been created. The name of the binary file is "KJOBCN1".

When the program is finished, both job control files should be placed in permanent storage; this could be automatic. The processing portion of the temperature model can now be started.

STRGEM - Stream Geometry Program. The STRGEM program merges the stream geometry, study, and hydrology node files into one composite network file. The program also inserts M nodes wherever there is an elevation drop of more than 300 m between nodes in the system.

The files used in the STRGEM program are: (1) "KJOBCN1" - produced in the job control update program; (2) stream geometry file; (3) study file; (4) hydrology node file; (5) meteorology file; and (6) the executable version of the STRGEM program. With these files in local working space, STRGEM is executed. The following information is printed at the terminal as the program runs.

STRGEM example

```
>>>>>>>>>>>>>>>>>>>>>>>>> ENTERING 'STRGEM' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
    BEGIN CALCULATING 'M' NODES AND AVERAGE ELEV. AND LAT.
    NORMAL COMPLETION OF 'ADDCHG'.
    BEGIN MERGING OUTPUT ('O') NODES INTO STREAM GEOMETRY FILE
    NORMAL COMPLETION OF 'ADDOUT'.
    BEGIN MERGING HYDROLOGY NODES INTO STREAM GEOMETRY FILE
    NORMAL COMPLETION OF 'ADDHYD'.
    STREAM GEOMETRY DATA IS LISTED ON FILE 'KVRSTRG'.
>>>>>>>>>>>>>>>>>>>>>>>>>> EXITING 'STRGEM' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
```

The first message is printed when the program starts. Next, the program inserts any M nodes that are required and computes average elevations and latitudes for the stream reaches. Stream geometry data for the M nodes are taken directly from the preceeding node. After the program completes these operations, the completion message is printed at the terminal.

The next operation is the merging of all O nodes into the system network. A completion message is printed at the terminal. The hydrology nodes are the last nodes added to the composite network. Stream geometry data for the O and hydrology only nodes are taken directly from the preceeding node. The completion message is printed at the terminal. For the example, the verification tables were requested and the program produced file "KVRSTRG". This readable output file contains the same merged network data as the binary file "KSTRMGM". The verification file should be checked to make sure the data are merging correctly.

Before proceeding to the next program, binary files "KSTRMGM" and "KJOBCN1" should be placed in permanent storage on your system.

HYDROL - Hydrology Program. The HYDROL program checks for missing hydrology data, fills in missing data using regression models, and computes lateral inflow where required. To execute the hydrology program, the following files are needed: (1) hydrology node file; (2) "KSTRMGM", created by the STRGEM program; (3) "KJOBCN1", created by STRGEM; (4) meteorology file; (5) time period file; (6) hydrology data file; and (7) the executable version of the HYDROL program. HYDROL will produce the files "KHYDROL" (binary), "KQSTATS" (binary), "KVRHYDR"(readable output), and an updated version of "KJOBCN1." With all the necessary input files in local working space, the program is executed. The following messages are printed at the terminal.

HYDROL example

```
>>>>>>>>>>>>>>>>>>>>>>>>> ENTERING 'HYDROL' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<
    BEGIN CHECKING FOR MISSING DATA IN HYDROLOGY FILE.
$$$-WARNING!  MISSING DATA IN REQUIRED KNOWN WATER TEMPERATURE FIELD. THE
    REQUESTED REGRESSION MODEL WILL BE USED TO FILL THE FOLLOWING MISSING
    REQUIRED KNOWN WATER TEMPERATURE FIELDS!
     STREAM       NODE    DIST.       YEAR      TIME      TYPE
      NAME        TYPE     (KM)                PERIOD     DATA
    NORMAL COMPLETION OF 'HYDFIL'.
    BEGIN COMPUTING LATERAL FLOW AND CREATING THE FINAL HYDROLOGY FILE.
    NORMAL COMPLETION OF 'LATFLO'.
    STREAM HYDROLOGY DATA IS LISTED ON FILE 'KVRHYDR'.
>>>>>>>>>>>>>>>>>>>>>>>>>> EXITING 'HYDROL' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
```

The first program checks for missing data in the hydrology data file. Any missing required water temperature data are flagged to be filled in with the water temperature regression model. Missing discharges are filled with the mean of the respective time period. When these steps are completed, the lateral flows are computed and the final hydrology file "KHYDROL" created. Discharge at all non-hydrology nodes are calculated directly from the preceed-ing node; also, lateral flow and associated temperatures are taken directly from the preceeding node. If the verification table for hydrology data is requested, the file "KVRHYDR" is created. This file contains much of the same information as the binary file. After the program is completed, the files "KJOBCN1", "KQSTATS", and "KHYDROL" are passed to the next programs.

<u>METROL - Meteorology Program</u>. The meteorology program calculates the meteorology data required for the network and produces a final file, merging all previous stream system information. The files needed to run this program are: (1) meteorology file; (2) time period file; (3) "KJOBCN1" from HYDROL; (4) "KSTRMGM" binary stream geometry file; (5) "KHYDROL" binary hydrology file; (6) shade file (required if shade model is used); and (7) the executable version of the METROL program.

The METROL program package will create the binary file "KMERGE" and the readable output file "KVRMETR." The job file "KJOBCN1" will be updated. With the required files in local working space, execute the METROL program. The following messages will be printed at the terminal:

METROL example

```
>>>>>>>>>>>>>>>>>>>>>>>>> ENTERING 'METROL' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
    BEGIN CALCULATING METEOROLOGY AND MERGE OPERATION.
    NORMAL COMPLETION OF 'METROL'.
    VERIFICATION OF MERGE IS ON FILE 'KVRMETR'.
>>>>>>>>>>>>>>>>>>>>>>>>>> EXITING 'METROL' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
```

The program first calculates the meteorology data for each time period, year and node in the composite network and then merges the meteorology data with the existing hydrology file to create the binary file "KMERGE." The verification file "KVRMETR" is the readable version of "KMERGE." When the program is completed, the files "KJOBCN1" and "KMERGE" are passed to the next program.

REGTWO - Water Temperature Regression Program. REGTWO fills in missing required water temperatures in the system. The regression analysis instructions are in the hydrology node file.

The files required to run REGTWO are: (1) time period file; (2) "KJOBCN1" binary job file from METROL; (3) "KMERGE" binary file from METROL; and (4) the executable version of the REGTWO program.

REGTWO creates the file "KVREGTW" and updates "KMERGE" with the regression temperatures. With the required input files in local working space, execute REGTWO. The following message is printed at the terminal:

REGTWO example

```
>>>>>>>>>>>>>>>>>>>>>>>>> ENTERING 'REGTWO' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
    BEGIN REGRESSION CALCULATIONS.
    NORMAL COMPLETION OF 'REGTWO'.
    REGRESSION VALIDATIONS ARE ON 'KVREGTW'.
>>>>>>>>>>>>>>>>>>>>>>>>>> EXITING 'REGTWO' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
```

The files "KJOBCN1" and "KMERGE" should be placed in permanent storage when the program is finished. With the completion of REGTWO, the necessary files have been created to calculate stream water temperatures.

TRNSPT - Heat Transport Program. TRNSPT calculates instream water temperatures using the physical process model described in Section 2 - Physical Processes and Math Model, of this report. The files required to run TRNSPT are: (1) "KMERGE" binary file of merged meteorology and hydrology data; (2) "KJOBCN1" binary job control file; (3) meteorology file; and (4) the executable version of TRNSPT. TRNSPT creates the files "KVRTRNS" (readable output file), "KTRNSPT" (binary output file), and "KVSTATS" (binary file of statistics). With the required files in local working space, execute TRNSPT. The following message is printed at the terminal:

TRNSPT example

```
>>>>>>>>>>>>>>>>>>>>>>>>> ENTERING 'TRNSPT' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
    BEGIN CALCULATING STREAM TEMPERATURES.
    NORMAL COMPLETION OF 'TRNSPT'.
    VERIFICATION OF TRNSPT IS ON FILE 'KVRTRNS'.
>>>>>>>>>>>>>>>>>>>>>>>>>> EXITING 'TRNSPT' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
```

All predicted instream water temperatures are written to the binary file "KTRNSPT." The file "KVSTATS" is used in the validation statistics program.

The binary file "KTRNSPT" is meant to be interfaced by the user with other software. All the necessary data are available in this file to easily recreate water temperatures anywhere in the network. Restrictions are only those imposed by the user when choosing the output spatial and temporial options. The user may wish to develop his own output program to display tables and graphics or to pass data to a subsequent program for further processing; e.g., habitat analysis. Water temperatures between nodes can be easily calculated using equations II(104) through II(112). The file format for "KTRNSPT" is given in Table III.21.

Table III.21. Binary-sequential KTRNSPT file format.

Record no.	Sequence no.	Type	Description
1	1	Character*80	From column 1-80, first record, job control file - title line
2	1	Character*80	From column 1-80, second record, job control file - subtitle line
3	1	Integer	From column 41-84, sixth record, job control file - starting year sequence number of output
	2	Integer	From column 49-56, sixth record, job control file - last year sequence number of output
	3	Integer	From column 57-64, sixth record, job control file - first time period sequence number of output
	4	Integer	From column 65-72, sixth record, job control file - last time period sequence number of output
	5	Integer	From column 73-80, sixth record, job control file - number of nodes in output table

Table III.21. (concluded)

Record no.	Sequence no.	Type	Description
- - - - -	Heat Transport Data by Node -		
4	1	Character*16	Stream name (16 characters)
	2	Character*8	Node type (8 characters)
	3	Real	Stream distance (km)
	4	Character*48	Remarks (48 characters)
	5	Real	Downstream average stream width (m)
	6	Real	Downstream n-value
	7	Real	Bed slope (decimal)
	8	Real	Local time from sunrise to sunset (hours)
	9	Real	Discharge at node (cms)
	10	Real	Mean daily water temperature at node (C)
	11	Real	Downstream lateral flow (cms/m)
	12	Real	Downstream lateral inflow temperature (C)
	13	Real	Mean daily equilibrium water temperature at node (C)
	14	Real	Mean daily first-order thermal exchange coefficient at node ($J/m^2/C$)
	15	Real	Mean daily second-order thermal exchange coefficient at node ($J/m^2/C^2$)
	16	Real	Maximum daily water temperature at node (C)
	17	Real	Maximum daily equilibrium water temperature at node (C)
	18	Real	Maximum daily first-order thermal exchange coefficient at node ($J/m^2/C$)

Note: Records 5, etc. repeat record 4 for the time periods, years, and nodes (see record 3, sequence numbers 1 through 5 above).

VSTATS - Validation Statistics Program. VSTATS calculates the differences between the predictions from the temperature model and the observed water temperatures at V and K nodes.

The files required for VSTATS are: (1) "KVSTATS" binary file produced in TRNSPT; (2) "KJOBCN1" binary job control file; (3) time period file; and (4) the executable version of VSTATS. The file "KVRSTAT" is created by VSTATS. The following message is printed at the terminal:

VSTATS example

```
>>>>>>>>>>>>>>>>>>>>>>>>>> ENTERING 'VSTATS' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
    BEGIN CALCULATING VALIDATION STATISTICS.
    NORMAL COMPLETION OF 'VSTATS'.
    VALIDATION STATISTICS ON FILE 'KVRSTAT'.
>>>>>>>>>>>>>>>>>>>>>>>>>>> EXITING 'VSTATS' PROGRAM <<<<<<<<<<<<<<<<<<<<<<<<<<
```

"KVRSTAT" is the readable output file containing the validation statistics for the temperature model run. This completes the temperature model execution.

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INSTREAM WATER TEMPERATURE MODEL
Part IV. Software Support Documentation

Fish and Wildlife Service

U.S. Department of the Interior

CONTENTS

FIGURES

TABLES

PART IV. SOFTWARE SUPPORT DOCUMENTATION

INTRODUCTION

A solution technique is a set of algorithms developed to be executed on a specific type or piece of hardware. Solution techniques developed for the instream water temperature model range from hand-held calculator programs that are designed for simple applications to a sophisticated FORTRAN 77 program designed for complex, large volumes of data or repetitive use for the same application.

Each solution technique was designed to solve one or more portions of the instream water temperature model on a unique type of hardware. For example, the FORTRAN 77 program was written for computer systems and essentially solves the entire instream water temperature model. When a choice between two different methods to solve the same physical process exists, the FORTRAN 77 program uses the preferred or more precise method; e.g., the atmospheric radiation model. On the other hand, hand-held calculator programs have such limited program capability that compromises had to be made regarding the scope of application and/or user convenience, but not in the accuracy of the results. Whenever desk-top calculator programs are applicable, the results are comparable to computer program results.

This part of the paper is subdivided into four sections, one for each specific solution technique.

HP-34C PROGRAM VERSION

Introduction

This section contains the HP-34C (or equivalent) source code listings (Fig. IV.1), register utilization (Table IV.1), a verification example (Table IV.2), and some additional mathematics necessary for this solution technique. Because the HP-34C (or equivalent) program version has no input mechanism other than keystrokes, it is necessary to enter the program instructions by hand. The verification example can be used to quickly check for errors. These instructions also work on an HP-15C. The necessary feature on small, hand-held calculators is an automatic root-finding algorithm (e.g., "SOLVE" on the HP series).

001-	Lbl A
002-006	$25 \cdot 10^{-4}$
007-	Rcl 6
008-	*
009-	Rcl 4
010-	*
011	Sto 6
012-	Rcl 3
013-	*
014-016	300
017-	-
018-019	25
020-	Rcl 4
021-	*
022-	Rcl 5
023-	$x \leftrightarrow y$
024-	Sto 5
025-	*
026-030	1.064
031-	Sto 4
032-	Rcl 3
033-	y^x
034-	*
035-	+
036-	1
037-	Rcl 2
038-	-
039-041	.95
042-	*
043-	Rcl 0
044-	*
045-	+
046-050	$55 \cdot 10^{-9}$
051-	Rcl 3
052-054	273
055-	+
056-	4
057-	y^x
058-	*
059-	Rcl 2
060-	*
061-	+
062-	Rcl 3
063-065	273
066-	+
067-	6
068-	y^x
069-	1
070-	Rcl 2
071-	-
072-	*
073-079	$514 \cdot 10^{-15}$
080-	*
081-	Rcl 1
082-	x^2
083-085	.17
086-	*
087-	1
088-	+
089-	*
090-	+
091-	Rcl I
092-094	2.5
095-	*
096-	+
097-	Sto 1
098-	Rcl 5
099-	Sto 2
100-	Rcl 6
101-	8
102-	+
103-	Sto 3
104-	0
105-	Enter
106-107	40
108-	Solve "0"
109-	Rcl 4
110-	$x \leftrightarrow y$
111-	y^x
112-115	.062
116-	*
117-	Rcl 2
118-	*
119-	Rcl 3
120-	+
121-	Sto 0
122-	Rtn
123-	Lbl 0
124-	Sto I
125-	Rcl 4
126-	Rcl I
127-	y^x
128-	Rcl 2
129-	*
130-	Rcl 3
131-	÷
132-	+
133-	Rcl 1
134-	Rcl 3
135-	÷
136-	-
137-	Rtn
138-	Lbl B
139-	÷
140-	÷
141-	Rcl 0
142-	*
143-148	$239 \cdot 10^{-6}$
149-	*
150-	CHS
151-	e^x
152-	$x \leftrightarrow y$
153-	Rcl I
154-	-
155-	*
156-	Rcl I
157	+
158	Rtn

Figure IV.1. HP-34C source code listing.

Table IV.1. HP-34C register utilization.

I	T_g, T_e
0	H_{sr}, K_1
1	C_ℓ, C
2	S, B
3	T_a, A
4	W_a, 1.0640
5	R_h, B
6	P, $(2.50 \cdot 10^{-3}\ PW_a)$

Note: Total program uses registers I and 0-6 and 158 program instruction steps.

Table IV.2. HP-34C verification example.

Given:

Reg.	Variable	Units (see conversions)	Remarks
0	H_{sg}	J/m²/sec	shortwave radiation (sunlight)
1	C_ℓ	decimal	cloud cover
2	S_h	decimal	stream shading
3	T_a	C	air temperature
4	W_a	m/sec	wind velocity
5	R_h	decimal	relative humidity
6	P	mb	atmospheric pressure
I	T_g	C	streambed temperature

Required: a. equilibrium stream temperature (T_e in C)

b. thermal exchange coefficient, K_1 (J/m²/sec/C)

Table IV.2. (continued)

Given:

Reg.	Variable	Units (see conversions)	Remarks

Solution: Algorithm for Subroutine A

1. $C = [2.50\bullet10^{-3}PW_aT_a - 300.00] + [25.00\ R_hW_a\ (1.0640)^{T_a}]$

$+ [0.95(1-S_h)H_{sr}] + [514\bullet10^{-15}(1-S_h)(1 + 0.17\ C_\ell^{2})\ (T_a+273)^{6}]$

$+ [5.50\bullet10^{-8}S\ (T_a + 273)^{4}] + [2.50\ T_g]$

2. $B = 25.00\ W_a$

3. $A = 2.50\bullet10^{-3}\ PW_a + 8.000$

4. $f(T_e) = T_e + [(B/A)\ (1.0640)^{T_e}] - [C/A] = 0$

5. $K_1 = A + [0.0620\ B\ (1.0640)^{T_e}]$

Output: a. T_e is in registers y and I

b. K_1 is in registers x and 0

I	T_e	C	equilibrium stream temperature
0	K_1	$J/m^2/sec/C$	thermal exchange coefficient

Stack

t	T_o	C	initial temperature (head of reach)
z	x_o	km	distance from head of reach
y	Q_o	cm/s	discharge
x	$\overline{B}$	m	average stream width

Required: water temperature at point x, T_w (C)

Table IV.2. (concluded)

Given:

Reg.	Variable	Units (see conversions)	Remarks

Solution: Algorithm for Subroutine B

$$T_w = T_e + \{(T_o - T_e) \exp [(-239 \cdot 10^{-6} K_1 \bar{B} x)/Q_o]\}$$

Output: T_w is in the x register

Basis for HP-34C Transport Temperature Model

Introduction. Part II contains the complete model; however, the restrictions inherent when using hand-held calculators require simplifications. The necessary simplifications to solve the heat transport math model follow.

Heat Flux Budget

$$H = H_a + H_c + H_d + H_e + H_s + H_v - H_w \qquad \text{IV(1)}$$

where $H \equiv$ net heat flux with respect to water

$H_a \equiv$ longwave atmospheric radiation into water

$H_c \equiv$ convection heat transfer across air-water interface

$H_d \equiv$ conduction heat transfer across water-streambed interface

$H_e \equiv$ heat exchange between evaporation and condensation

$H_s \equiv$ shortwave solar radiation into water

$H_v \equiv$ longwave vegetation radiation into water

$H_w \equiv$ water back radiation

Subsidary Heat Flux Relationships ($J/m^2/sec$):

$$H_a = 5.14 \cdot 10^{-13} (1-S_h) (1 + 0.17 C_\ell^2) (T_a + 273)^6 \qquad \text{IV(2)}$$

$$H_c = 2.50 \cdot 10^{-3} PW_a (T_a - T_w) \qquad \text{IV(3)}$$

$$H_d = 2.5\ (T_g - T_w) \quad \text{IV(4)}$$

$$H_e = 25.00\ W_a\ [R_h\ (1.0640)^{T_a} - (1.0640)^{T_w}] \quad \text{IV(5)}$$

$$H_s = 0.95\ (1-S_h)\ H_{sg} \quad \text{IV(6)}$$

$$H_v = 5.50 \bullet 10^{-8} S_h\ (T_a + 273)^4 \quad \text{IV(7)}$$

$$H_w = 300.00 + 5.500 T_w \quad \text{IV(8)}$$

where C_ℓ ≡ cloud cover (decimal)

H_{sg} ≡ solar radiation at ground level ($J/m^2/sec$)

P ≡ air pressure (mb)

R_h ≡ relative humidity (decimal)

S_h ≡ stream shading (decimal)

T_a ≡ air temperature (C)

T_g ≡ streambed temperature (at 2 ft depth) (C)

T_w ≡ water temperature (C) at point x

W_a ≡ wind speed (m/sec)

Substituting equations IV(2) through IV(6) into equation IV(1) and rearranging:

$$H = \{ (2.50 \bullet 10^{-3}\ PW_a + 8.000)\ T_w\} + \{ (25.00W)\ (1.0640)^{T_w}\}$$
$$- \{ [5.14 \bullet 10^{-13}\ (1-S_h)\ (1 + 0.17\ C_\ell^{\ 2})\ (T_a + 273)^6] + [0.95\ (1-S_h)\ H_{sg}]$$
$$- [300.00] + [25.00 R_h W_a\ (1.0640)^{T_a}] + [2.50^{-3}\ PWT_a] + [2.50 T_g]$$
$$+ [5.50 \bullet 10^{-8} S_h\ (T_a + 273)^4]\} \quad \text{IV(9)}$$

let $C = [5.14 \bullet 10^{-13}\ (1-S)\ (1 + 0.17 C_\ell^{\ 2})\ (T_a + 273)^6] + [0.95\ (1-S_h) H_{sg}]$

$$- [300.00] + [25.00 R_h W_a\ (1.0640)^{T_a}] + [2.50^{-3} PW_a T_a] + [2.5 T_g] \quad \text{IV(10)}$$

$$B = 25.00 W_a \quad \text{IV(11)}$$

$$A = 2.50 \bullet 10^{-3} PW_a + 8.000 \quad \text{IV(12)}$$

Substituting equations IV(10) through IV(12) into equation IV(8):

$$H = A\,T_w + B\,(1.0640)^{T_w} - C \qquad \text{IV(13)}$$

Equilibrium Water Temperature, T_e:

As $x \to \infty$, $T_w \to T_e$ and $H = \Sigma H_i = 0$

Therefore, substituting $H = 0$ and $T_e = T_w$ in equation IV(13):

$$A\,T_e + B\,(1.0640)^{T_e} - C = 0 \qquad \text{IV(14)}$$

The solution of equation IV(14) for T_e, given A, B, and C, is the equilibrium water temperature of the stream; i.e., as the water flows downstream, the water temperature approaches the equilibrium temperature asymptotically.

Heat Transfer Equation

The governing equation for heat transfer is:

$$dT_w/dt = H/(\rho c_p d) \qquad \text{IV(15)}$$

where c_p ≡ specific heat of water

d ≡ water depth

H ≡ net heat flux of water

T_w ≡ water temperature at point x

t ≡ travel time of water

ρ ≡ density of water

The travel time of water can be expressed in terms of the water velocity (v) and stream distance (x):

$$dt = dx/v \qquad \text{IV(16)}$$

Substituting equation IV(16) into equation IV(15) and rearranging:

$$dT_w/H = dx/(\rho c_p v d) \qquad \text{IV(17)}$$

To analytically solve equation IV(17) in closed form, it is necessary to express H as a function of T_w; therefore, equation IV(13) is used and a Taylor series expansion taken about T_e.

A first-order Taylor series expansion about T_e is:

$$H(T_w) = H(T_e) + \{(dH/dT_w)|_{T_e} (T_e - T_w)\} \qquad \text{IV(18)}$$

The first derivative of equation IV(13) evaluated at T_e is:

$$dH/dT_w|_{T_e} = A + \{B[\ln(1.0640)] (1.0640)^{T_e}\} \qquad \text{IV(19)}$$

The net heat flux at T_e is zero; i.e.,

$$H(T_e) = 0 \qquad \text{IV(20)}$$

Substituting equations IV(19) and IV(20) into equation IV(17):

$$H(T_w) = K(T_e - T_w) \qquad \text{IV(21)}$$

where

$$K_1 = A + B\,[\ln(1.0640)]\,(1.0640)^{T_e} \qquad \text{IV(22)}$$

By this definition, K_1 is a first-order Taylor series thermal exchange coefficient.

Substituting equation IV(21) into equation IV(17), letting T_o represent the upstream boundary condition, and integrating:

$$T_w = T_e + \{(T_o - T_e)\exp[-(K_1 x_o)/(\rho c_p vd)]\} \qquad \text{IV(23)}$$

Letting $\rho = 1000\ kg/m^3$

$c_p = 4182\ J/kg/C$

$Q_o/\bar{B} = vd$

and expressing x_o in km:

$$T_w = T_e + \{(T_o - T_e)\exp[-(239 \cdot 10^{-6} K_1 \bar{B} x_o)/(Q_o)]\} \qquad \text{IV(24)}$$

where $\bar{B}$ ≡ stream width (m)

K_1 ≡ thermal exchange coefficient defined by equation IV(22) ($J/m^2/sec/C$)

T_e ≡ equilibrium water temperature from equation IV(14) (C)

T_o ≡ upstream boundary condition water temperature (C)

T_w ≡ water temperature at point x (C)

Q_o ≡ stream discharge (cms)

x_o ≡ downstream distance from boundary condition point (km)

HP-41C PROGRAM VERSION

Introduction

This section contains: (1) instructions for the HP-41C solution technique user; (2) variable name lists for all input/output variables; (3) register utilization for each program; and (4) a source code listing for each program.

Thirty-five magnetic cards are necessary for the entire package. Cards for each program are available from:

Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Creekside One Building
2627 Redwing Road
Fort Collins, CO 80526-2899

Solution Techniques Instructions

The following instructions in Table IV.3 are presented in the HP-41 printer format as they would appear when using the cassette-drive mass storage device. The instructions are for use with all five HP-41C programs.

Table IV.3. HP-41C instructions.

INSTRUCTIONS

THE INSTREAM WATER TEMPERATURE--HP-41C PROGRAMS, DATED 12/81--WERE DEVELOPED BY FRED D. THEURER WHILE WORKING WITH THE INSTREAM FLOW GROUP (IFG).

THIS SET OF INSTRUCT-IONS AND VARIABLE NAME LIST ARE TO ASSIST THE USER TO UNDERSTAND AND EXECUTE THE SEPARATE PROGRAMS.

THERE ARE FIVE MODEL PROGRAMS. THEY ARE:

1. SHADE
2. SOLRAD
3. STDREG
4. TRNREG
5. WATRAN

SHADE IS THE SOLAR SHADE MODEL TO DETERMINE THE TOPOGRAPHIC AND RI-PARIAN VEGETATION SHADE FACTORS.

SOLRAD IS THE SOLAR RADIATION MODEL TO:
(1) CALIBRATE THE DUST AND GROUND REFLECTIVITY COEFFICIENTS, AND
(2) PREDICT THE EXTRA-TERRESTRIAL SOLAR RADIA-TION AND OTHER NEEDED SOLAR-RELATED PARAMETERS.

STDREG IS A STANDARD MULTIPLE REGRESSION MODEL.

TRNREG IS A TRANSFORMED REGRESSION MODEL. BOTH ARE USED WITH KNOWN METEOROLOGIC AND HYDROLOGIC (Q'S & TW'S) DATA AT A STATION TO SMOOTH AND/OR COMPLETE DATA SETS. THE REGRESSION MODELS CAN BE USED FOR: (1) PREDICTING INITIAL WATER TEMPERATURE CONDITIONS AT HEADWATERS; (2) PREDICTING CERTAIN PHYSICAL PARAMETERS ABOVE A GAGE; (3) VALIDATING PHYSICAL MODELED WATER TEMPERATURES AT INTERIOR NETWORK STATIONS; AND (4) CALIBRATING THE PHYSICAL-PROCESS MODEL AT INTERIOR NETWORK STATIONS.

WATRAN IS A COMBINATION HEAT FLUX-HEAT TRANSPORT MODEL FOR A SINGLE REACH. METEOROLOGIC DATA IS AUTOMATICALLY ADJUSTED FOR ELEVATION DIFFERENCES BETWEEN THE METEOROLOGIC STATION AND THE STUDY REACH. AVERAGE DAILY, MAXIMUM DAYTIME, AND MINIMUM NIGHTIME WATER TEMPERATURES ARE PREDICTED AT ANY USER-SPECIFIED DOWNSTREAM DISTANCE OR SERIES OF DISTANCES. AVERAGE DAILY WATER TEMPERATURE VERSUS DOWNSTREAM DISTANCE PLOTS ARE ALSO POSSIBLE.

VARIABLE NAME LIST

ALL UNITS ARE IN THE SCIENTIFIC (METRIC) SYSTEM. THE UNITS USED ARE:
ANGLES-RADIANS, R
      -DEG.MIN, D.M
DIMENSIONLESS-DECIMAL, D
HEAT-JOULES, J
LENGTH-METERS, M
      -KILOMETERS, KM
TEMPERATURE-CELIUS, C
TIME-SECONDS, S
    -HOURS, H

THE FOLLOWING VARIABLES ARE USED IN ONE OR MORE OF THE FOUR HP-41C SUBMODELS. THE FORMAT IS SYMBOL:DESCRIPTION, UNIT

AR :STREAM AZIMUTH, R

aS :SUNRISE/SUNSET ALT., R

aTE :EASTSIDE TOPO. ALT., R

aTW :WESTSIDE TOPO. ALT., R

B :AVG. STREAM WIDTH, MD

d :DUST COEF., D

d1 :MIN. DUST COEF., D

d2 :MAX. DUST COEF., D

H :HEAT FLUX, J/M2/S

HA :ATMOSPHERIC

HC :AIR CONVECTION

HD :STREAM BED CONDUCION

HE :EVAPORATION

HF :FLUID FRICTION

HS :SOLAR CORRECTED FOR ATMOSPHERE, CLOUDS, REFLECTION, & SHADE

HSA :SOLAR CORRECTED FOR ATMOSPHERE ONLY

HSC :SOLAR CORRECTED FOR CLOUD COVER ONLY

HSG :SOLAR CORRECTED FOR ATM. AND CLOUDS (AT GROUND LEVEL)

HSW :SOLAR CORRECTED FOR ATM, CLOUDS, AND REFLECTION

HSX :EXTRA-TERRESTRIAL SOLAR RADIATION

HV :RIPARIAN VEGETATION

HW :BACK RADIATION FROM WATER

K1 :FIRST-ORDER THERMAL EXCHANGE COEF., J/M2/S/C

K2 :SECOND-ORDER THERMAL EXCHANGE COEF., J/M2/S/C/C

LAT :LATITUDE, D.M

MP :OPTICAL AIR MASS, D

N :MANNING'S N-VALUE

QB :BRANCH DISCHARGE, CMS

QJ :JUNCTION DISCHARGE, CMS

QL :LATERAL FLOW, CMS/KM

QO :INITIAL DISCHARGE, CMS

QT :TRIBUTARY DISCHARGE, CMS

R :COEF. OF MULTIPLE DETERMINATION, D

RG :GROUND REFLECTIVITY D

RG1 :MIN. GROUND REFLECTIVITY, D

RG2 :MAX. GROUND REFLECTIVITY, D

RH :RELATIVE HUMIDITY, D

SF :ENERGY GRADIENT, M/M

SH :TOTAL SHADE FACTOR, D

SO :AVG. DAILY SUNSHINE DURATION, H

ST :TOPOGRAPHIC SHADE FACTOR, D

ST :STANDARD DEVIATION OF RECORDED WATER TEMPERATURES, C

ST.X:STANDARD DEVIATION OF WATER TEMPERATURES REGRESSED ON TRANSFORMED INDEPENDENT VARIABLES X, C

SV :RIPARIAN SHADE FACTOR, D

S/SO:SUNSHINE RATIO, D

TA :AVG. DAILY AIR TEMPERATURE, C

TB :BRANCH WATER TEMPERATURE, C

TE :EQUILIBRIUM WATER TEMPERATURE, C

TJ :JUNCTION WATER TEMPERATURE, C

TN :MIN. NIGHTTIME WATER TEMPERATURE, C

TO :INITIAL WATER TEMPERATURE, C

TT :TRIBUTARY WATER TEMPERATURE, C

TW :AVG. DAILY WATER TEMPERATURE, C

TW,e:EXPONENTIAL REGRESSION PREDICTION WATER TEMPERATURE, C

TW,X:LINEAR REGRESSION PREDICTION WATER TEMPERATURE, C

TX :MAX. DAYTIME WATER TEMPERATURE, C

TY :AVG. ANNUAL AIR TEMPERATURE, C

EASTSIDE VEG.

VCE :CROWN FACTOR, M

VDE :DENSITY, D

VHE :HEIGHT, M

VOE :OFFSET, M

WESTSIDE VEG.

VCW :CROWN FACTOR, M

VDW :DENSITY, D

VHW :HEIGHT, M

VOW	:OFFSET, M
WA	:AVG. DAILY WIND SPEED, M/S
X	:DOWNSTREAM CHANNEL DISTANCE, KM
XO	:UPSTREAM CHANNEL DISTANCE TO SOURCE, KM
X1	:1ST REG. COEF.
X2	:2ND REG. COEF.
X3	:3RD REG. COEF.
X4	:4TH REG. COEF.
X5	:5TH REG. COEF.
ZA	:AVG. REACH ELEVATION, M
ZO	:METEOROLOGIC STATION ELEVATION, M
δ	:PROBABLE ERROR, C

The HP-41C verson of the instream water temperature solar shade model is the first of the desk-top calculator stand-alone programs. The register utilization is given in Table IV.4 and the source coding is show in Figure IV.2.

This program has applications: (1) as a basis for managing the riparian vegetation where experienced judgement can be used to set shade criteria; (2) as a first step in using the complete HP-41C version programs; and (3) as a separate step to develop shade data for other programs.

Table IV.4. Instream water temperature solar shade model.
Size 057

Reg.	Description	Reg.	Description
00	1.031 - January (1st time per.)	21	γ_{tw} - west side topo. angle
01	32.059 - February (2nd time per.)	22	V_{cw} - west side crown measurement
02	60.090 - March (3rd time per.)	23	V_{hw} - west side vegetation; height
03	91.120 - April (4th time per.)	24	V_{ow} - west side vegetation offset
04	121.151 - May (5th time per.)	25	V_{dw} - west side vegetation density
05	152.181 - June (6th time per.)	26	$\Sigma\bar{\alpha}_s$ - avg. solar altitude
06	182.212 - July (7th time per.)	27	ΣS_t - topo. shade
07	213.243 - August (8th time per.)	28	ΣS_v - veg. shade
08	244.273 - September (9th time per.)	29	time period loop
09	274.304 - October (10th time per.)	30	day loop
10	305.334 - November (11th time per.)	31	hour loop
11	335.365 - December (12th time per.)	32	δ_i - current declination
12	Φ - latitude	33	sin Φ
13	A_r - stream agimuth	34	cos Φ
14	$\bar{B}$ - average stream width	35	sin δ_i
15	α_{te} - east side topo. angle	36	cos δ_i
16	V_{ce} - east side crown measurement	37	sin Φ sin δ_i
17	V_{he} - east side vegetation height	38	cos Φ cos δ_i
18	V_{oe} - east side vegetation offset	39	A_{zo}
19	V_{de} - east side vegetation density	40	H_{sx}
20	Σ ($V_d B_s$ sin γ)	41	Cos A_z Cos Φ, Δh

Table IV.4. (concluded)

Reg.	Description	Reg.	Description
42	tan α_{tx}	50	Az
43	tan α_{ti}	51	A_{zsr}, sin α_s
44	α_{sx}	52	A_{zss}, cos α_s
45	α_{to}	53	H_{rso}
46	A_{zmn}, $\Sigma\ \alpha_s$	54	H_{rsr}
47	A_{zmx}	55	H_{rss}
48	$f(\alpha_s)$, hr	56	ΣI
49	α_s		

Flag	Description	Flag clear	Flag set
00	Input angle	Deg. min	Radians
01	sunrise/set	set	rise
02	global trace	no	yes
03	sunrise/set - stream azimuth	$\lvert A_r \rvert > A_{zo}$	$\lvert A_r \rvert \leq A_{zo}$
04	sunrise/set	$A_z \geq 0$	$A_z < 0$
05	temporary trace	no	yes
06	east/west side	$A_r > A_y$	$A_r \leq A_y$
07	temporary trace	no	yes
08	time period	day	months
09	Simpson's rule	interior point	end point
10	Simpson's rule	single weight	double weight

```
01♦LBL "SHADE"
02 CLRG
03 CF 29
04 RAD
05 FIX 0
06 "TRACE:Y/N?"
07 AVIEW
08 CF 02
09 AON
10 STOP
11 ASTO X
12 AOFF
13 "Y"
14 ASTO Y
15 X=Y?
16 SF 02
17 "ANGLES:D/R?"
18 AVIEW
19 CF 00
20 AON
21 STOP
22 ASTO X
23 AOFF
24 "R"
25 ASTO Y
26 X=Y?
27 SF 00
28 "TIME PER:M/D?"
29 AVIEW
30 SF 08
31 AON
32 STOP
33 ASTO X
34 AOFF
35 "D"
36 ASTO Y
37 X=Y?
38 CF 08
39 ADV
40 ":R=?"
41 ASTO 00
42 ":D,M=?"
43 ASTO 01
44 ":M=?"
45 ASTO 02
46 "LAT"
47 FS? 00
48 ARCL 00
49 FC? 00
50 ARCL 01
51 PROMPT
52 FS? 00
53 GTO 00
54 HR
55 D-R
56♦LBL 00
57 STO 12
58 SIN
59 STO 33
60 RCL 12
61 COS
62 STO 34
63 "AR"
64 FS? 00
65 ARCL 00
66 FC? 00
67 ARCL 01
68 PROMPT
69 FS? 00
70 GTO 00
71 HR
72 D-R
73♦LBL 00
74 STO 13
75 "B"
76 ARCL 02
77 PROMPT
78 STO 14
79 "aTE"
80 FS? 00
81 ARCL 00
82 FC? 00
83 ARCL 01
84 PROMPT
85 FS? 00
86 GTO 00
87 HR
88 D-R
89♦LBL 00
90 STO 15
91 TAN
92 STO 42
93 "VCE"
94 ARCL 02
95 PROMPT
96 STO 16
97 "VHE"
98 ARCL 02
99 PROMPT
100 STO 17
101 "VOE"
102 ARCL 02
103 PROMPT
104 STO 18
105 "VDE:D=?"
106 PROMPT
107 STO 19
108 "aTW"
109 FS? 00
110 ARCL 00
111 FC? 00
112 ARCL 01
113 PROMPT
114 FS? 00
115 GTO 00
116 HR
117 D-R
118♦LBL 00
119 STO 21
120 TAN
121 STO 43
122 "VCW"
123 ARCL 02
124 PROMPT
125 STO 22
126 "VHW"
127 ARCL 02
128 PROMPT
129 STO 23
130 "VOW"
131 ARCL 02
132 PROMPT
133 STO 24
134 "VDW:D=?"
135 PROMPT
136 STO 25
137♦LBL 99
138 ADV
139 ADV
140 FC? 08
141 GTO 00
142 1.031
143 STO 00
144 32.059
145 STO 01
146 60.090
147 STO 02
148 91.120
149 STO 03
150 121.151
```

Figure IV.2. HP-41C source code listing for the solar shade model.

```
151 STO 04
152 152.181
153 STO 05
154 182.212
155 STO 06
156 213.243
157 STO 07
158 244.273
159 STO 08
160 274.304
161 STO 09
162 305.334
163 STO 10
164 335.365
165 STO 11
166 "MONTH:NO.=?"
167 PROMPT
168 STO 29
169 .011
170 STO 30
171 "INC:DAY=?"
172 PROMPT
173 1 E5
174 /
175♦LBL 01
176 ST+ IND 30
177 ISG 30
178 GTO 01
179 GTO 03
180♦LBL 00
181 12
182 "TIME PER.:NO.=?"
183 PROMPT
184 X>Y?
185 X<>Y
186 1 E3
187 /
188 1
189 +
190 STO 29
191 STO 30
192♦LBL 02
193 ADV
194 FIX 0
195 RCL 30
196 INT
197 "TIME PER. NO. "
198 ARCL X
199 AVIEW
200 "DAYS"
201 ARCL X
202 "├:JUL.=?"
203 1
204 -
205 PROMPT
206 STO IND Y
207 ISG 30
208 GTO 02
209♦LBL 03
210 ADV
211 ADV
212 FIX 0
213 0
214 STO 26
215 STO 27
216 STO 28
217 STO 56
218 RCL 29
219 INT
220 FS? 08
221 "MONTH NO. "
222 FC? 08
223 "TIME PER. NO. "
224 ARCL X
225 AVIEW
226 1
227 -
228 RCL IND X
229 STO 30
230♦LBL 04
231 SF 01
232 CF 09
233 1
234 ST+ 56
235 RCL 30
236 INT
237 FIX 0
238 "DAY= "
239 ARCL X
240 FC? 02
241 CF 21
242 ADV
243 AVIEW
244 SF 21
245 FIX 6
246 XEQ D
247 XEQ E
248 XEQ F
249 XEQ G
250 STO 55
251 CHS
252 STO 54
253 RCL 53
254 RCL 37
255 *
256 RCL 53
257 SIN
258 RCL 38
259 *
260 +
261 2
262 *
263 STO 40
264♦LBL 00
265 RCL 15
266 X≠0?
267 GTO 05
268 RCL 21
269 X=0?
270 GTO 06
271♦LBL 05
272 CF 03
273 RCL 39
274 RCL 13
275 ABS
276 X<=Y?
277 SF 03
278 FC? 03
279 XEQ A
280 FS? 03
281 XEQ B
282 FS? 09
283 GTO 14
284 XEQ C
285 CF 04
286 RCL 50
287 X<0?
288 SF 04
289 XEQ H
290 FS? 01
291 STO 54
292 FC? 01
293 STO 55
294 FS?C 01
295 GTO 05
296♦LBL 06
297 1
298 RCL 55
299 RCL 54
300 -
```

Figure IV.2. (continued)

```
301 RCL 37
302 *
303 RCL 55
304 SIN
305 RCL 54
306 SIN
307 -
308 RCL 38
309 *
310 +
311 RCL 40
312 /
313 -
314 ST+ 27
315 FC? 02
316 GTO 00
317 ADV
318 "ST= "
319 ARCL X
320 AVIEW
321♦LBL 00
322 SF 01
323 SF 04
324 SF 09
325 SF 10
326 .016
327 STO 31
328 0
329 STO 20
330 RCL 44
331 STO 46
332 RCL 55
333 RCL 54
334 -
335 16
336 /
337 STO 41
338 X=0?
339 GTO 08
340 0
341 STO 46
342♦LBL 07
343 FC?C 10
344 SF 10
345 16
346 RCL 31
347 INT
348 X=Y?
349 SF 09
350 RCL 41
351 *
352 RCL 54
353 +
354 STO 48
355 X>0?
356 CF 04
357 COS
358 RCL 38
359 *
360 RCL 37
361 +
362 ASIN
363 1 E-9
364 X<=Y?
365 X<>Y
366 STO 49
367 COS
368 STO 52
369 RCL 49
370 ST+ 46
371 FS? 10
372 ST+ 46
373 SIN
374 STO 51
375 RCL 33
376 *
377 RCL 35
378 -
379 RCL 34
380 /
381 RCL 52
382 /
383 ACOS
384 FS? 04
385 CHS
386 STO 50
387 RCL 13
388 X<=Y?
389 CF 01
390 -
391 SIN
392 ABS
393 RCL 52
394 *
395 RCL 51
396 /
397 FS? 01
398 RCL 17
399 FC? 01
400 RCL 23
401 *
402 FS? 01
403 RCL 16
404 FC? 01
405 RCL 22
406 2
407 /
408 FS? 01
409 RCL 18
410 FC? 01
411 RCL 24
412 -
413 +
414 RCL 14
415 X>Y?
416 X<>Y
417 0
418 X<=Y?
419 X<>Y
420 RCL 51
421 *
422 FS? 01
423 RCL 19
424 FC? 01
425 RCL 25
426 *
427 ST+ 20
428 FS? 10
429 ST+ 20
430 FC?C 09
431 GTO 00
432 2
433 /
434 ST- 20
435 RCL 49
436 2
437 /
438 ST- 46
439♦LBL 00
440 ISG 31
441 GTO 07
442 1.5
443 ST/ 41
444 RCL 20
445 RCL 41
446 *
447 RCL 14
448 RCL 40
449 *
450 /
```

Figure IV.2. (continued)

```
451 ST+ 28
452 STO 47
453♦LBL 08
454 FC? 02
455 GTO 00
456 "SV= "
457 ARCL X
458 AVIEW
459♦LBL 00
460 RCL 44
461 RCL 46
462 X=Y?
463 GTO 00
464 RCL 41
465 *
466 RCL 55
467 RCL 54
468 -
469 /
470 STO 46
471 -
472 RCL 47
473 *
474 RCL 46
475 +
476♦LBL 00
477 ST+ 26
478 FC? 02
479 GTO 00
480 "aL= "
481 ARCL X
482 AVIEW
483 ADV
484♦LBL 00
485 ISG 30
486 GTO 04
487 RCL 56
488 ST/ 20
489 ST/ 26
490 ST/ 27
491 ST/ 28
492 RCL 29
493 1
494 -
495 RCL IND X
496 FIX 0
497 "FROM: DAY= "
498 ARCL X
499 AVIEW
500 STO Y
501 FRC
502 1000
503 *
504 X=0?
505 RCL Y
506 "THRU: DAY= "
507 ARCL X
508 AVIEW
509 ADV
510 FIX 2
511 RCL 26
512 R-D
513 HMS
514 "aS = "
515 ARCL X
516 "⊦ D.M"
517 AVIEW
518 FIX 4
519 RCL 27
520 "ST = "
521 ARCL X
522 "⊦ D"
523 AVIEW
524 RCL 28
525 "SV = "
526 ARCL X
527 "⊦ D"
528 AVIEW
529 +
530 "SH = "
531 ARCL X
532 "⊦ D"
533 AVIEW
534♦LBL 14
535 ISG 29
536 GTO 03
537 ADV
538 BEEP
539 GTO 99
540♦LBL D
541 172
542 X<>Y
543 -
544 PI
545 *
546 182.5
547 /
548 COS
549 .40928
550 *
551 STO 32
552 FC? 02
553 GTO 00
554 "DECL= "
555 ARCL X
556 AVIEW
557♦LBL 00
558 SIN
559 STO 35
560 RCL 33
561 *
562 STO 37
563 RCL 32
564 COS
565 STO 36
566 RCL 34
567 *
568 STO 38
569 RTN
570♦LBL E
571 RCL 37
572 RCL 38
573 +
574 ASIN
575 STO 44
576 FC? 02
577 RTN
578 "aSX= "
579 ARCL X
580 AVIEW
581 RTN
582♦LBL F
583 0
584 STO 50
585 CF 05
586 FS? 02
587 SF 05
588 FS? 05
589 CF 02
590 XEQ b
591 STO 45
592 FS? 05
593 SF 02
594 FC? 02
595 RTN
596 "aT0= "
597 ARCL X
598 AVIEW
599 RTN
600♦LBL G
```

Figure IV.2. (continued)

```
601 !
602 RCL 35
603 RCL 34
604 /
605 CHS
606 X>Y?
607 X<>Y
608 -1
609 X<=Y?
610 X<>Y
611 ACOS
612 STO 39
613 FC? 02
614 GTO 00
615 "AZ0= "
616 ARCL X
617 AVIEW
618♦LBL 00
619 RCL 37
620 RCL 38
621 /
622 CHS
623 ACOS
624 STO 53
625 FC? 02
626 RTN
627 "HRS0= "
628 ARCL X
629 AVIEW
630 RTN
631♦LBL A
632 RCL 44
633 RCL 45
634 X<=Y?
635 GTO 00
636 0
637 STO 46
638 STO 47
639 RTN
640♦LBL 00
641 FC? 01
642 GTO 00
643 RCL 39
644 CHS
645 STO 46
646 0
647 STO 47
648 RTN
649♦LBL 00
650 0
651 STO 46
652 RCL 39
653 STO 47
654 RTN
655♦LBL B
656 FC? 01
657 GTO 09
658 CF 09
659 RCL 44
660 RCL 45
661 X<=Y?
662 GTO 00
663 RCL 39
664 PI
665 RCL 13
666 X>0?
667 -
668 X<=0?
669 +
670 ABS
671 X>Y?
672 GTO 00
673 SF 09
674 "DOUBLE SUNSHINE"
675 "├ PERIOD"
676 AVIEW
677 "EXECUTION STOPP"
678 "├ED THIS"
679 AVIEW
680 "TIME PERIOD"
681 AVIEW
682 RTN
683♦LBL 00
684 RCL 39
685 CHS
686 STO 46
687 RCL 13
688 STO 47
689 X<=0?
690 RTN
691♦LBL 00
692 RCL 44
693 RCL 45
694 X>Y?
695 GTO 00
696 0
697 STO 47
698 RTN
699♦LBL 00
700 0
701 STO 46
702 RTN
703♦LBL 09
704 RCL 39
705 STO 47
706 RCL 13
707 STO 46
708 X>0?
709 RTN
710♦LBL 00
711 RCL 44
712 RCL 45
713 X>Y?
714 GTO 00
715 0
716 STO 46
717 RTN
718♦LBL 00
719 0
720 STO 47
721 RTN
722♦LBL C
723 FS? 02
724 ADV
725 RCL 46
726 RCL 47
727 +
728 2
729 /
730 STO 50
731 CF 07
732 FS? 02
733 SF 07
734 FS? 07
735 CF 02
736 XEQ b
737 STO 49
738 .020
739 STO 31
740♦LBL 10
741 XEQ a
742 XEQ b
743 CF 05
744 RCL 49
745 X>Y?
746 SF 05
747 RCL 50
748 FC? 01
749 GTO 11
750 FS? 05
```

Figure IV.2. (continued)

```
751 STO 47
752 FC? 05
753 STO 46
754 GTO 12
755♦LBL 11
756 FS? 05
757 STO 46
758 FC? 05
759 STO 47
760♦LBL 12
761 RCL 46
762 RCL 47
763 +
764 2
765 /
766 STO 50
767 -
768 ABS
769 1 E-6
770 X>Y?
771 GTO 00
772 ISG 31
773 GTO 10
774♦LBL 00
775 XEQ b
776 STO 49
777 FS? 07
778 SF 02
779 FC? 02
780 RTN
781 FS? 01
782 "aLSR= "
783 FC? 01
784 "aLSS= "
785 ARCL 49
786 AVIEW
787 FS? 01
788 "AZSR= "
789 FC? 01
790 "AZSS= "
791 ARCL 50
792 AVIEW
793 RTN
794♦LBL a
795 RCL 50
796 COS
797 RCL 34
798 *
799 STO 41
800♦LBL 13
801 RCL 49
802 SIN
803 RCL 33
804 *
805 RCL 49
806 COS
807 RCL 41
808 *
809 -
810 RCL 35
811 -
812 STO 48
813 RCL 33
814 RCL 49
815 COS
816 *
817 RCL 41
818 RCL 49
819 SIN
820 *
821 +
822 /
823 ST- 49
824 ABS
825 1 E-6
826 X<=Y?
827 GTO 13
828 RCL 48
829 ABS
830 X>Y?
831 GTO 13
832 RCL 49
833 FC? 02
834 RTN
835 "aLS= "
836 ARCL X
837 AVIEW
838 RTN
839♦LBL b
840 RCL 50
841 RCL 13
842 CF 06
843 X<=Y?
844 SF 06
845 -
846 SIN
847 ABS
848 FC? 06
849 RCL 42
850 FS? 06
851 RCL 43
852 *
853 ATAN
854 FC? 02
855 RTN
856 "aLT= "
857 ARCL X
858 AVIEW
859 RTN
860♦LBL H
861 RCL 49
862 SIN
863 RCL 37
864 -
865 RCL 38
866 /
867 1
868 X>Y?
869 X<>Y
870 ACOS
871 FS? 04
872 CHS
873 FC? 02
874 RTN
875 FS? 01
876 "HRSR= "
877 FC? 01
878 "HRSS= "
879 ARCL X
880 AVIEW
881 RTN
882 END
```

Figure IV.2. (concluded)

The HP-41C version of the instream water temperature solar radiation model is the second of the desk-top calculator stand-alone programs. The register utilization is given in Table IV.5 and the source coding is shown in Figure IV.3.

This program can be used: (1) to develop solar radiation data for other programs; (2) as the second step in using the complete HP-41C version programs; and/or (3) to calibrate certain solar parameters such as the dust and ground reflectivity coefficients.

Table IV.5. Instream water temperature solar radiation model.

Size 124

Reg.	Description		Reg.	Description
00	D_i	current Julian Day	01	LBL06 daily loop
02	LBL05	monthly loop	03	month request
04	LBL04	reach loop	05	reach request
06	N	number of reaches	07	LBL07 - dew point loop
08	ϕ	current reach latitude	09	Z current reach elevation
10	α_s	local sunrise/sunset altitude	11	d current reach dust coef.
12	R_g	current reach ground coef.	13	δ current day declination
14	$(\sin\phi\sin\delta)$, $\bar{m}_p$		15	$(\cos\phi\cos\delta)$, $e^{-\eta z}$
16	$\bar{h}_s$ - avg. time per. sunrise/ sunset hour angle		17	$\bar{\alpha}$ - avg. time period solar altitude
18	$\bar{H}_{sx}$ - avg. extraterrestrial sol. rad.		19	ΣI - avg. time period solar altitude
20	273.16, 1-a'		21	1.0640, a"
22	1.031 - Jan.		23	32.059 - Feb.
24	60.090 - Mar.		25	91.120 - Apr.
26	121.151 - May		27	152.181 - Jun.

Table IV.5. (concluded)

Reg.	Description	Reg.	Description
28	182.212 - Jul.	29	213.243 - Aug.
30	244.273 - Sep.	31	274.304 - Oct.
32	305.334 - Nov.	33	335.365 - Dec.
34	T_{a1} - Jan. air temp.	45	T_{a12} - Dec. air temp.
46	R_{g1} - Jan. relative humidity	57	R_{g12} - Dec. relative humidity
58	S/S_{o1} - Jan. sunshine	69	S/S_{o12} - Dec. sunshine
70	d_1 - Jan., d min. - dust coef.	81	d_{12} - Dec., d max. - dust coef.
82	R_{g1} - Jan., R_g min. - grnd. coef.	93	R_{g12} - Dec., d max. - grnd. coef.
	Reach No. 1		Reach No. N
94	ϕ_1 - latitude	93 + N	ϕ_N - latitude
94 + N	Z_1 - elevation	93 + 2N	Z_N - elevation
94 + 2N	α_{s1} - local sunrise/sunset alt.	93 + 3N	α_{sN} - local sunrise/sunset alt.

Flag	Use	Flag clear	Flag set
00	time periods ?	days	months
01	dust and ground coef.?	annual distribution	time period (months)
02	subroutine/fall thru?	subroutine	fall thru
03	subroutine/fall thru?	subroutine	fall thru

This program requires seven magnetic cards.

```
01+LBL "SOLRAD"
02 CLRG
03 CF 29
04 RAD
05 ADV
06 "TIME PER:M/D?"
07 AVIEW
08 "R/S MONTHS"
09 AVIEW
10 "D DAYS"
11 AVIEW
12 SF 00
13 AON
14 STOP
15 ASTO X
16 AOFF
17 "D"
18 ASTO Y
19 X=Y?
20 CF 00
21 ADV
22 "d, RG:T/A?"
23 AVIEW
24 "R/S TIME PER."
25 AVIEW
26 "A ANN. DIST."
27 AVIEW
28 SF 01
29 AON
30 STOP
31 ASTO X
32 AOFF
33 "A"
34 ASTO Y
35 X=Y?
36 CF 01
37+LBL 00
38 FIX 0
39 FS? 01
40 GTO 00
41 ADV
42 "d MIN:D=?"
43 PROMPT
44 STO 70
45 "d MAX:D=?"
46 PROMPT
47 STO 81
48 ADV
49 "RG MIN:D=?"
50 PROMPT
51 STO 82
52 "RG MAX:=?"
53 PROMPT
54 STO 93
55+LBL 00
56 ADV
57 10
58 "NO. REACHS=?"
59 PROMPT
60 X>Y?
61 X<>Y
62 STO 06
63 1 E3
64 /
65 1
66 +
67 STO 04
68 STO 05
69+LBL 01
70 ADV
71 RCL 04
72 "REACH NO. "
73 ARCL X
74 AVIEW
75 93
76 +
77 "LAT"
78 ARCL 04
79 "⊢:D.M=?"
80 PROMPT
81 HR
82 D-R
83 STO IND Y
84 X<>Y
85 RCL 06
86 +
87 "ELEV"
88 ARCL 04
89 "⊢:M=?"
90 PROMPT
91 STO IND Y
92 X<>Y
93 RCL 06
94 +
95 "aS"
96 ARCL 04
97 "⊢:D.M=?"
98 PROMPT
99 HR
100 D-R
101 STO IND Y
102 ISG 04
103 GTO 01
104 ADV
105+LBL 02
106 ADV
107 FIX 0
108 0
109 STO 00
110 RCL 05
111 STO 04
112 FC? 00
113 GTO 00
114 "MONTHS:NO.=?"
115 PROMPT
116 STO 02
117 STO 03
118 "INC:DAY=?"
119 PROMPT
120 1 E5
121 /
122 STO 00
123 1.031
124 STO 22
125 32.059
126 STO 23
127 60.090
128 STO 24
129 91.120
130 STO 25
131 121.151
132 STO 26
133 152.181
134 STO 27
135 182.212
136 STO 28
137 213.243
138 STO 29
139 244.273
140 STO 30
141 274.304
142 STO 31
143 305.334
144 STO 32
145 335.365
146 STO 33
147 GTO 03
148+LBL 00
149 12
150 "TIME PER.:NO.=?"
```

Figure IV.3. HP-41C source code listing for the solar radiation model.

```
151 PROMPT
152 X>Y?
153 X<>Y
154 1 E3
155 /
156 1
157 +
158 STO 02
159 STO 03
160♦LBL 03
161 ADV
162 FS? 00
163 "MONTH NO. "
164 FC? 00
165 "TIME PER. NO. "
166 ARCL 02
167 AVIEW
168 RCL 02
169 21
170 +
171 RCL 00
172 ST+ IND Y
173 FS? 00
174 GTO 00
175 X<>Y
176 "DAYS"
177 ARCL 02
178 "⊢:JUL.=?"
179 PROMPT
180 STO IND Y
181♦LBL 00
182 33
183 RCL 02
184 +
185 "TA"
186 ARCL 02
187 "⊢:C=?"
188 PROMPT
189 STO IND Y
190 SF 03
191 "RH"
192♦LBL 04
193 X<>Y
194 12
195 +
196 ARCL 02
197 "⊢:D=?"
198 PROMPT
199 STO IND Y
200 FC?C 03
201 RTN
202 "S/S0"
203 XEQ 04
204 FC? 01
205 GTO 00
206 "d"
207 XEQ 04
208 "RG"
209 XEQ 04
210♦LBL 00
211 ISG 02
212 GTO 03
213♦LBL 05
214 ADV
215 ADV
216 ADV
217 RCL 03
218 STO 02
219 FIX 0
220 "  REACH NO. "
221 ARCL 04
222 AVIEW
223 RCL 04
224 93
225 +
226 RCL IND X
227 STO 08
228 X<>Y
229 RCL 06
230 +
231 RCL IND X
232 STO 09
233 X<>Y
234 RCL 06
235 +
236 RCL IND X
237 STO 10
238♦LBL 06
239 ADV
240 ADV
241 FIX 0
242 FS? 00
243 "MONTH NO. "
244 FC? 00
245 "TIME PER. NO. "
246 ARCL 02
247 AVIEW
248 0
249 STO 11
250 STO 12
251 STO 16
252 STO 17
253 STO 18
254 STO 19
255 RCL 02
256 21
257 +
258 RCL IND X
259 STO 01
260 FC? 01
261 GTO 07
262 RCL 02
263 69
264 +
265 RCL IND X
266 STO 11
267 X<>Y
268 12
269 +
270 RCL IND X
271 STO 12
272♦LBL 07
273 1
274 ST+ 19
275 FIX 0
276 RCL 01
277 INT
278 STO 00
279 "DAY= "
280 ARCL X
281 CF 21
282 AVIEW
283 SF 21
284♦LBL 00
285 172
286 RCL 00
287 -
288 365
289 /
290 2
291 *
292 PI
293 *
294 COS
295 .40928
296 *
297 STO 13
298♦LBL 00
299 RCL 10
300 SIN
```

Figure IV.3. (continued)

```
301 RCL 08
302 SIN
303 RCL 13
304 SIN
305 *
306 STO 14
307 -
308 RCL 08
309 COS
310 RCL 13
311 COS
312 *
313 STO 15
314 /
315 1
316 X>Y?
317 X<>Y
318 ACOS
319 STO Y
320 ST+ 16
321•LBL 00
322 RCL 14
323 *
324 RCL 15
325 RCL Z
326 SIN
327 *
328 +
329 RCL 00
330 2
331 -
332 2
333 *
334 PI
335 *
336 365
337 /
338 COS
339 .01672
340 *
341 1
342 +
343 X↑2
344 .99972
345 /
346 *
347 1377
348 *
349 PI
350 /
351 ST+ 18
352•LBL 00
353 RCL Y
354 2
355 /
356 COS
357 RCL 15
358 *
359 RCL 14
360 +
361 ASIN
362 ST+ 17
363•LBL 00
364 FS? 01
365 GTO 00
366 SF 02
367 RCL 00
368 213
369 -
370 RCL 81
371 RCL 70
372•LBL 08
373 STO T
374 -
375 X<>Y
376 365
377 /
378 PI
379 *
380 ABS
381 SIN
382 *
383 +
384 FC?C 02
385 RTN
386 ST+ 11
387 RCL 00
388 244
389 -
390 RCL 93
391 RCL 82
392 XEQ 08
393 ST+ 12
394•LBL 00
395 ISG 01
396 GTO 07
397•LBL 00
398 RCL 19
399 FC? 01
400 ST/ 11
401 FC? 01
402 ST/ 12
403 ST/ 16
404 ST/ 17
405 ST/ 18
406•LBL 00
407 RCL 02
408 21
409 +
410 RCL IND X
411 "FROM: DAY= "
412 ARCL X
413 AVIEW
414 STO Y
415 FRC
416 1000
417 *
418 X=0?
419 RCL Y
420 "THRU: DAY= "
421 ARCL X
422 AVIEW
423 ADV
424 FIX 1
425 "HSX= "
426 ARCL 18
427 "⊦ J/M2/S"
428 AVIEW
429•LBL 00
430 288
431 .0065
432 RCL 09
433 *
434 -
435 288
436 /
437 5.256
438 Y↑X
439 RCL 17
440 R-D
441 3.885
442 +
443 -1.253
444 Y↑X
445 .15
446 *
447 RCL 17
448 SIN
449 +
450 /
```

Figure IV.3. (continued)

```
STO 14
♦LBL 00
1.004
STO 07
RCL 02
33
+
273.16
STO 20
1.0640
STO 21
RCL IND Z
Y↑X
X<>Y
RCL IND Z
+
/
12
ST+ Z
RDN
RCL IND Y
*
STO 15
LN
RCL 21
LN
/
♦LBL 09
RCL 20
+
RCL 15
*
LN
RCL 21
LN
/
ISG 07
GTO 09
♦LBL 00
.0614
*
.110
+
E↑X
.85
*
.134
*
.465
+
RCL 14
*
CHS
STO 15
-.880
RCL 14
*
E↑X
.171
*
.129
+
*
E↑X
1
X<>Y
-
STO 20
♦LBL 00
-.721
RCL 14
*
E↑X
.421
*
.179
+
RCL 15
*
E↑X
STO 21
♦LBL 00
RCL 20
RCL 11
-
2
/
+
1
RCL 20
RCL 11
+
2
/
RCL 12
*
-
/
STO 15
ST* 18
♦LBL 00
RCL 02
57
+
RCL IND X
2
3
/
Y↑X
.78
*
.22
+
ST* 18
♦LBL 00
FIX 4
"1-AP="
ARCL 20
"├ D"
AVIEW
"APP= "
ARCL 21
"├ D"
AVIEW
"a  = "
ARCL 17
"├ R"
AVIEW
"d  = "
ARCL 11
"├ D"
AVIEW
"RG = "
ARCL 12
"├ D"
AVIEW
RCL 16
PI
/
24
*
FIX 3
"S0 = "
ARCL X
"├ HR"
AVIEW
FIX 1
"HSG= "
ARCL 18
"├ J/M2/S"
```

Figure IV.3. (continued)

```
601 AVIEW
602♦LBL 00
603 ISG 02
604 GTO 06
605 ISG 04
606 GTO 05
607 BEEP
608 GTO 02
609 .END.
```

Figure IV.3. (concluded)

The HP-41C version of the instream water temperature standard regression model is the third of the desk-top calculator stand-alone programs. The register utilization is given in Table IV.6 and the source coding is shown in Figure IV.4.

This program can be used to generate water temperature data at a point where sufficient water temperature data already exists. The generated values can be used to: (1) smooth existing data sets; (2) fill-in missing data; and (3) generate values for applicable scenarios.

The independent variables for this version are limited to linear terms of air temperature, wind speed, relative humidity, sunshine ratio, solar radiation, and discharge.

Table IV.6. Instream water temperature standard regression model.

Size 086

Reg.	Description	Reg.	Description
00	T_w	01	T_a
02	W_a	03	R_h
04	H_{sx}	05	S/S_o
06	Q	07	Used by XROM "PVT"
08	Used by XROM "PVT"	09	Used by XROM "PVT"
10	Used by XROM "PVT"	11	Used by XROM "PVT"
12	Used by XROM "PVT"	13	Used by XROM "PVT"
14	7 - order of matrix	15	N
16	ΣT	17	ΣW
18	ΣR	19	ΣH
20	ΣS	21	ΣQ
22	ΣT	23	ΣT^2
24	ΣTW	25	ΣTR
26	ΣTH	27	ΣTS

Table IV.6. (continued)

Reg.	Description	Reg.	Description
28	ΣTQ	29	ΣW
30	ΣWT	31	ΣW^2
32	ΣWR	33	ΣWH
34	ΣWS	35	ΣWQ
36	ΣR	37	ΣRT
38	ΣRW	39	ΣR^2
40	ΣRH	41	ΣRS
42	ΣRQ	43	ΣH
44	ΣHT	45	ΣHW
46	ΣHR	47	ΣH^2
48	ΣHS	49	ΣHQ
50	ΣS	51	ΣST
52	ΣSW	53	ΣSR
54	ΣSH	55	ΣS^2
56	ΣSQ	57	ΣQ
58	ΣQT	59	ΣQW
60	ΣQR	61	ΣQH
62	ΣQS	63	ΣQ^2
64	Used by XROM "PVT"	65	Used by XROM "PVT"
66	Used by XROM "PVT"	67	Used by XROM "PVT"
68	Used by XROM "PVT"	69	Used by XROM "PVT"
70	Used by XROM "PVT"	71	ΣT_W
72	$\Sigma T_W T$	73	$\Sigma T_W W$

Table IV.6. (concluded)

Reg.	Description	Reg.	Description
74	$\Sigma T_w R$	75	$\Sigma T_w H$
76	$\Sigma T_w S$	77	$\Sigma T_w Q$
78	ΣT_w	79	$\Sigma T_w T$
80	$\Sigma T_w W$	81	$\Sigma T_w R$
82	$\Sigma T_w H$	83	$\Sigma T_w S$
84	$\Sigma T_w Q$	85	ΣT_w^2

Flag	Use	Flag clear	Flag set
00	new/correction	new data	correction data
01	not used	----	----
02	minimum set?	yes	no
03	regression coefficients?	no	yes

This program requires four magnetic cards.

```
01♦LBL "STDREG"
02 CLRG
03 CLST
04 .010
05 STO 00
06♦LBL "*"
07 CF IND 00
08 ISG 00
09 GTO "*"
10 SF 02
11 SF 04
12 SF 05
13 SF 21
14 SF 27
15 CF 29
16 0
17 STO 00
18 7
19 STO 14
20♦LBL "NEWDAT"
21 CF 00
22 FS? 03
23 GTO "TW"
24 XEQ "NPUT"
25 XEQ "ΣXI"
26 RCL 14
27 RCL 15
28 1
29 +
30 X>Y?
31 CF 02
32 GTO "NEWDAT"
33♦LBL "CORDAT"
34 SF 00
35 FS? 03
36 GTO "TW"
37 XEQ "NPUT"
38 XEQ "ΣXI"
39 GTO "NEWDAT"
40♦LBL "TW"
41 FS? 02
42 GTO "NEWDAT"
43 FC? 03
44 XEQ "REG"
45♦LBL 03
46 XEQ "NPUT"
47 RCL 71
48 RCL 72
49 RCL 01
50 *
51 +
52 RCL 73
53 RCL 02
54 *
55 +
56 RCL 74
57 RCL 03
58 *
59 +
60 RCL 75
61 RCL 04
62 *
63 +
64 RCL 76
65 RCL 05
66 *
67 +
68 RCL 77
69 RCL 06
70 *
71 +
72 FIX 2
73 "TW EST.="
74 ARCL X
75 "⊦ C"
76 AVIEW
77 GTO 03
78♦LBL "NPUT"
79 ADV
80 ADV
81 FIX 0
82 RCL 15
83 1
84 +
85 "INPUT SET "
86 FC? 03
87 ARCL X
88 AVIEW
89 "TA:C=?"
90 PROMPT
91 STO 01
92 "WA:M/S=?"
93 PROMPT
94 STO 02
95 "RH:DEC=?"
96 PROMPT
97 STO 03
98 "HSX:J/M2/S=?"
99 PROMPT
100 STO 04
101 "S/S0:DEC=?"
102 PROMPT
103 STO 05
104 "Q:CMS=?"
105 PROMPT
106 STO 06
107 FS? 03
108 RTN
109 "TW:C=?"
110 PROMPT
111 STO 00
112 RTN
113♦LBL "ΣXI"
114 1
115 FS? 00
116 CHS
117 ST+ 15
118 RCL 00
119 FS? 00
120 CHS
121 ST+ 71
122 X↑2
123 FS? 00
124 CHS
125 ST+ 85
126 RCL 01
127 FS? 00
128 CHS
129 ST+ 16
130 X↑2
131 FS? 00
132 CHS
133 ST+ 23
134 RCL 01
135 RCL 02
136 *
137 FS? 00
138 CHS
139 ST+ 24
140 RCL 01
141 RCL 03
142 *
143 FS? 00
144 CHS
145 ST+ 25
146 RCL 01
147 RCL 04
148 *
149 FS? 00
150 CHS
```

Figure IV.4. HP-41C source code listing for the standard regression model.

```
151 ST+ 26
152 RCL 01
153 RCL 05
154 *
155 FS? 00
156 CHS
157 ST+ 27
158 RCL 01
159 RCL 06
160 *
161 FS? 00
162 CHS
163 ST+ 28
164 RCL 01
165 RCL 00
166 *
167 FS? 00
168 CHS
169 ST+ 72
170 RCL 02
171 FS? 00
172 CHS
173 ST+ 17
174 X↑2
175 FS? 00
176 CHS
177 ST+ 31
178 RCL 02
179 RCL 03
180 *
181 FS? 00
182 CHS
183 ST+ 32
184 RCL 02
185 RCL 04
186 *
187 FS? 00
188 CHS
189 ST+ 33
190 RCL 02
191 RCL 05
192 *
193 FS? 00
194 CHS
195 ST+ 34
196 RCL 02
197 RCL 06
198 *
199 FS? 00
200 CHS
201 ST+ 35
202 RCL 02
203 RCL 00
204 *
205 FS? 00
206 CHS
207 ST+ 73
208 RCL 03
209 FS? 00
210 CHS
211 ST+ 18
212 X↑2
213 FS? 00
214 CHS
215 ST+ 39
216 RCL 03
217 RCL 04
218 *
219 FS? 00
220 CHS
221 ST+ 40
222 RCL 03
223 RCL 05
224 *
225 FS? 00
226 CHS
227 ST+ 41
228 RCL 03
229 RCL 06
230 *
231 FS? 00
232 CHS
233 ST+ 42
234 RCL 03
235 RCL 00
236 *
237 FS? 00
238 CHS
239 ST+ 74
240 RCL 04
241 FS? 00
242 CHS
243 ST+ 19
244 X↑2
245 FS? 00
246 CHS
247 ST+ 47
248 RCL 04
249 RCL 05
250 *
251 FS? 00
252 CHS
253 ST+ 48
254 RCL 04
255 RCL 06
256 *
257 FS? 00
258 CHS
259 ST+ 49
260 RCL 04
261 RCL 00
262 *
263 FS? 00
264 CHS
265 ST+ 75
266 RCL 05
267 FS? 00
268 CHS
269 ST+ 20
270 X↑2
271 FS? 00
272 CHS
273 ST+ 55
274 RCL 05
275 RCL 06
276 *
277 FS? 00
278 CHS
279 ST+ 56
280 RCL 05
281 RCL 00
282 *
283 FS? 00
284 CHS
285 ST+ 76
286 RCL 06
287 FS? 00
288 CHS
289 ST+ 21
290 X↑2
291 FS? 00
292 CHS
293 ST+ 63
294 RCL 06
295 RCL 00
296 *
297 FS? 00
298 CHS
299 ST+ 77
300 RTN
```

Figure IV.4. (continued)

```
301♦LBL "REG"
302 RCL 15
303 STO 00
304 RCL 16
305 STO 22
306 RCL 17
307 STO 29
308 RCL 18
309 STO 36
310 RCL 19
311 STO 43
312 RCL 20
313 STO 50
314 RCL 21
315 STO 57
316 RCL 24
317 STO 30
318 RCL 25
319 STO 37
320 RCL 26
321 STO 44
322 RCL 27
323 STO 51
324 RCL 28
325 STO 58
326 RCL 32
327 STO 38
328 RCL 33
329 STO 45
330 RCL 34
331 STO 52
332 RCL 35
333 STO 59
334 RCL 40
335 STO 46
336 RCL 41
337 STO 53
338 RCL 42
339 STO 60
340 RCL 48
341 STO 54
342 RCL 49
343 STO 61
344 RCL 56
345 STO 62
346 RCL 71
347 STO 78
348 RCL 72
349 STO 79
350 RCL 73
351 STO 80
352 RCL 74
353 STO 81
354 RCL 75
355 STO 82
356 RCL 76
357 STO 83
358 RCL 77
359 STO 84
360 FIX 9
361 XROM "PVT"
362 RCL 00
363 STO 15
364 RCL 71
365 RCL 78
366 *
367 RCL 72
368 RCL 79
369 *
370 +
371 RCL 73
372 RCL 80
373 *
374 +
375 RCL 74
376 RCL 81
377 *
378 +
379 RCL 75
380 RCL 82
381 *
382 +
383 RCL 76
384 RCL 83
385 *
386 +
387 RCL 77
388 RCL 84
389 *
390 +
391 RCL 71
392 X↑2
393 RCL 15
394 /
395 -
396 RCL 85
397 RCL 71
398 X↑2
399 RCL 15
400 /
401 -
402 /
403 SQRT
404 FIX 4
405 "R"
406 XEQ 01
407 X↑2
408 1
409 X<>Y
410 -
411 SQRT
412 RCL 85
413 RCL 15
414 *
415 RCL 78
416 X↑2
417 -
418 RCL 15
419 /
420 RCL 15
421 1
422 -
423 /
424 SQRT
425 FIX 3
426 "ST:C"
427 XEQ 01
428 *
429 "ST.X:C"
430 XEQ 01
431 .6745
432 *
433 "d:C"
434 XEQ 01
435 RTN
436♦LBL 01
437 "⊢= "
438 ARCL X
439 AVIEW
440 RTN
441 END
```

Figure IV.4. (concluded)

The HP-41C version of the instream water temperature transformed regression model is the fourth of the desk-top calculator stand-alone programs. The register utilization is given in Table IV.7 and the source coding is shown in Figure IV.5.

This program can be used to generate water temperature data at a point where sufficient water temperature data already exists. The generated values can be used to: (1) smooth existing data sets; (2) fill-in missing data; and (3) generate values for applicable scenarios.

This version is limited to a second-order approximation of the power series for the exponential.

Table IV.7. Instream water temperature transformed regression model.

Size 064

Reg.	Use	Reg.	Use
00	K, Z_1	01	T_{ao}, T_a, T_e, Z_2
02	R_{ho}, R_h, X_1	03	W_{ao}, W_a, X_2
04	$S/S_o, X_3$	05	H_{sx}, H_{sw}, X_4
06	$\bar{\alpha}, X_1X_2$	07	d, X_1X_3
08	R_g, X_1X_4	09	Q, X_2X_3
10	w, X_2X_4	11	m_p, X_3X_4
12	1-a'	13	a"
14	5 (order of matrix)	15	N=no. data sets
16	ΣX_1	17	ΣX_2
18	ΣX_3	19	ΣX_4
20	ΣX_1	21	ΣX_1^2
22	ΣX_1X_2	23	ΣX_1X_3
24	ΣX_1X_4	25	ΣX_2
26	ΣX_2X_1	27	ΣX_2^2
28	ΣX_1X_3	29	ΣX_1X_3

Table IV.7. (continued)

Reg.	Use	Reg.	Use
30	ΣX_3	31	ΣX_3X_1
32	ΣX_3X_2	33	$\Sigma X_3{}^2$
34	ΣX_3X_4	35	ΣX_4
36	$\Sigma X_4, X_1$	37	ΣX_4X_2
38	ΣX_4X_3	39	$\Sigma X_4{}^2$
40	T_i, T_w	41	A, T_iX_1
42	B, T_iX	43	C, T_iX_3
44	D, T_iX_4	45	$\Sigma T_i, a_0$
46	$\Sigma T_iX_1, a_1$	47	$\Sigma T_iX_2, a_2$
48	$\Sigma T_iX_3, a_3$	49	$\Sigma T_iX_4, a_4$
50	$\overline{B}$	51	1.0640
52	Z_0, P	53	$Z_a, \Delta T$
54	S_f	55	S_h
56	T_{no}, T_g	57	$\Sigma T_i, T_o$
58	$\Sigma T_iX_1, x_o$	59	$\Sigma T_iX_2, K_1$
60	$\Sigma T_iX_3, T_e$	61	ΣT_iX_4
62	$\Sigma T_i{}^2$	63	273.16

Flag	Use	Flag clear	Flag set
00	new/corr. data?	correction	new
01	measured/calc. T_w?	calc.	measured
02	min. data sets?	N≥5	N<5
03	used by XROM	$\Sigma X, T$	"PVT"

Table IV.7. (concluded)

Reg.	Use	Reg.	Use
04	used by XROM	ΣX,T	"PVT"
05	used by XROM	ΣX,T	"PVT"

This program requires eight magnetic cards.

```
01♦LBL "TRNREG"
02 RAD
03 CLRG
04 CLST
05 5
06 STO 14
07 1.0640
08 STO 51
09 273.16
10 STO 63
11 CF 01
12 SF 02
13 CF 03
14 SF 04
15 SF 05
16 SF 21
17 SF 27
18 CF 29
19 "NO"
20 ASTO Y
21 "KNOWN TW?"
22 AVIEW
23 AON
24 "R/S=YES"
25 AVIEW
26 "NO=NO"
27 PROMPT
28 ASTO X
29 AOFF
30 X=Y?
31 SF 01
32♦LBL "STRMDAT"
33 ADV
34 FIX 0
35 "STRM. DATA"
36 AVIEW
37 "ZA:M=?"
38 PROMPT
39 STO 53
40 "B :M=?"
41 PROMPT
42 STO 50
43 "SH:DEC=?"
44 PROMPT
45 STO 55
46 "SF:M/M=?"
47 PROMPT
48 STO 54
49 FC? 01
50 GTO "STACNST"
51 "T0:C=?"
52 PROMPT
53 STO 57
54 "X0:KM=?"
55 PROMPT
56 STO 58
57♦LBL "STACNST"
58 ADV
59 "STA. CONST."
60 AVIEW
61 "Z0:M=?"
62 PROMPT
63 STO 52
64 "TY:C=?"
65 PROMPT
66 STO 56
67♦LBL 00
68 RCL 52
69 RCL 53
70 -
71 .00656
72 *
73 ST+ 56
74 288
75 RCL 53
76 .0065
77 *
78 -
79 288
80 /
81 5.256
82 Y↑X
83 1013
84 *
85 STO 52
86 RDN
87 STO 53
88♦LBL "NEWDAT"
89 CF 00
90 FS? 03
91 GTO "TW"
92 XEQ "NPUT"
93 RCL 14
94 RCL 15
95 1
96 +
97 X>Y?
98 CF 02
99 GTO "NEWDAT"
100♦LBL "CORDAT"
101 SF 00
102 FS? 03
103 GTO "TW"
104 XEQ "NPUT"
105 GTO "NEWDAT"
106♦LBL "TW"
107 FS? 02
108 GTO "NEWDAT"
109 FC? 03
110 XEQ "T0X0"
111♦LBL 03
112 XEQ "NPUT"
113 RCL 45
114 RCL 46
115 RCL 02
116 *
117 +
118 RCL 47
119 RCL 03
120 *
121 +
122 RCL 48
123 RCL 04
124 *
125 +
126 RCL 49
127 RCL 05
128 *
129 +
130 STO 40
131 RCL 57
132 -
133 RCL 40
134 RCL 01
135 +
136 *
137 X<0?
138 GTO 00
139 RCL 01
140 CHS
141 STO 40
142♦LBL 00
143 FIX 2
144 RCL 40
145 "TW,X:C"
146 XEQ 88
147 XEQ "TWe"
148 "TW,e:C"
149 XEQ 88
150 GTO 03
```

Figure IV.5. HP-41C source code listing for the transformed regression model.

```
151•LBL "NPUT"
152 ADV
153 ADV
154 FIX 0
155 RCL 15
156 1
157 +
158 "INPUT SET "
159 FC? 03
160 ARCL X
161 AVIEW
162 "TA:C=?"
163 PROMPT
164 STO 01
165 "WA:M/S=?"
166 PROMPT
167 STO 03
168 "RH:DEC=?"
169 PROMPT
170 STO 02
171 "HSX:J/M*M/S=?"
172 PROMPT
173 STO 05
174 "a:RAD=?"
175 PROMPT
176 STO 06
177 "d:DEC=?"
178 PROMPT
179 STO 07
180 "RG:DEC=?"
181 PROMPT
182 STO 08
183 "S/S0:DE=?"
184 PROMPT
185 STO 04
186 "Q:CMS=?"
187 PROMPT
188 STO 09
189 FS? 01
190 GTO 00
191 FS? 03
192 GTO 00
193 "TW:C=?"
194 PROMPT
195 STO 40
196•LBL 00
197 XEQ "LAP"
198 XEQ "MP"
199 XEQ "W"
200 XEQ "a1"
201 XEQ "a2"
202 XEQ "eNZ"
203 ST* 05
204 XEQ "eCL"
205 ST* 05
206 XEQ "RT"
207 1
208 X<>Y
209 -
210 ST* 05
211 XEQ "ABCD"
212 20
213 STO 01
214•LBL "TE"
215 RCL 01
216 RCL 63
217 +
218 X↑2
219 X↑2
220 RCL 41
221 *
222 RCL 01
223 RCL 42
224 *
225 +
226 RCL 51
227 RCL 01
228 Y↑X
229 RCL 43
230 *
231 +
232 RCL 44
233 -
234 RCL 63
235 RCL 01
236 +
237 3
238 Y↑X
239 RCL 41
240 *
241 4
242 *
243 RCL 42
244 +
245 RCL 51
246 RCL 01
247 Y↑X
248 RCL 51
249 LN
250 *
251 RCL 43
252 *
253 +
254 STO 00
255 /
256 ST- 01
257 ABS
258 1 E-5
259 X<=Y?
260 GTO "TE"
261 ADV
262 FIX 2
263 RCL 01
264 STO 60
265 "TE:C"
266 XEQ 88
267 RCL 00
268 STO 59
269 "K1:J/M*M/S/C"
270 XEQ 88
271 FC? 01
272 GTO 00
273 FS? 03
274 GTO 00
275 XEQ "TWe"
276 STO 40
277 "TW:C"
278 XEQ 88
279•LBL 00
280 RCL 00
281 RCL 50
282 *
283 RCL 09
284 /
285 -4.182 E6
286 /
287 STO 00
288 RCL 01
289 CHS
290 STO 01
291 RCL 00
292 STO 02
293 STO 03
294 X↑2
295 STO 04
296 STO 05
297 RCL 01
298 ST* 03
299 ST* 05
300 FS? 03
```

Figure IV.5. (continued)

```
301 RTN
302♦LBL "ΣXI"
303 RCL 02
304 STO 06
305 STO 07
306 STO 08
307 STO 41
308 FS? 00
309 CHS
310 ST+ 16
311 X↑2
312 FS? 00
313 CHS
314 ST+ 21
315 RCL 03
316 ST* 06
317 STO 09
318 STO 10
319 STO 42
320 FS? 00
321 CHS
322 ST+ 17
323 X↑2
324 FS? 00
325 CHS
326 ST+ 27
327 RCL 04
328 ST* 07
329 ST* 09
330 STO 11
331 STO 43
332 FS? 00
333 CHS
334 ST+ 18
335 X↑2
336 FS? 00
337 CHS
338 ST+ 33
339 RCL 05
340 ST* 08
341 ST* 10
342 ST* 11
343 STO 44
344 FS? 00
345 CHS
346 ST+ 19
347 X↑2
348 FS? 00
349 CHS
350 ST+ 39
351 RCL 06
352 FS? 00
353 CHS
354 ST+ 22
355 RCL 07
356 FS? 00
357 CHS
358 ST+ 23
359 RCL 08
360 FS? 00
361 CHS
362 ST+ 24
363 RCL 09
364 FS? 00
365 CHS
366 ST+ 28
367 RCL 10
368 FS? 00
369 CHS
370 ST+ 29
371 RCL 11
372 FS? 00
373 CHS
374 ST+ 34
375 RCL 40
376 ST* 41
377 ST* 42
378 ST* 43
379 ST* 44
380 FS? 00
381 CHS
382 ST+ 45
383 X↑2
384 FS? 00
385 CHS
386 ST+ 62
387 RCL 41
388 FS? 00
389 CHS
390 ST+ 46
391 RCL 42
392 FS? 00
393 CHS
394 ST+ 47
395 RCL 43
396 FS? 00
397 CHS
398 ST+ 48
399 RCL 44
400 FS? 00
401 CHS
402 ST+ 49
403 1
404 FS? 00
405 CHS
406 ST+ 15
407 RTN
408♦LBL "T0X0"
409 RCL 15
410 STO 00
411 RCL 16
412 STO 20
413 RCL 17
414 STO 25
415 RCL 18
416 STO 30
417 RCL 19
418 STO 35
419 RCL 22
420 STO 26
421 RCL 23
422 STO 31
423 RCL 24
424 STO 36
425 RCL 28
426 STO 32
427 RCL 29
428 STO 37
429 RCL 34
430 STO 38
431 RCL 45
432 STO 57
433 RCL 46
434 STO 58
435 RCL 47
436 STO 59
437 RCL 48
438 STO 60
439 RCL 49
440 STO 61
441 SCI 4
442 XROM "PVT"
443 RCL 00
444 STO 15
445 RCL 45
446 RCL 57
447 *
448 RCL 46
449 RCL 58
450 *
```

Figure IV.5. (continued)

```
451 +
452 RCL 47
453 RCL 59
454 *
455 +
456 RCL 48
457 RCL 60
458 *
459 +
460 RCL 49
461 RCL 61
462 *
463 +
464 RCL 45
465 X↑2
466 RCL 15
467 /
468 -
469 RCL 62
470 RCL 45
471 X↑2
472 RCL 15
473 /
474 -
475 /
476 SQRT
477 FIX 4
478 "R"
479 XEQ 88
480 X↑2
481 1
482 X<>Y
483 -
484 SQRT
485 RCL 62
486 RCL 15
487 *
488 RCL 57
489 X↑2
490 -
491 RCL 15
492 /
493 RCL 15
494 1
495 -
496 /
497 SQRT
498 FIX 3
499 "ST:C"
500 XEQ 88
501 *
502 "ST.X:C"
503 XEQ 88
504 .6745
505 *
506 "d:C"
507 XEQ 88
508 ADV
509 FIX 2
510 RCL 45
511 STO 57
512 "T0:C "
513 XEQ 88
514 RCL 47
515 1 E3
516 /
517 STO 58
518 "X0:KM"
519 XEQ 88
520 RTN
521♦LBL "TWe"
522 1
523 RCL 59
524 RCL 50
525 *
526 RCL 58
527 *
528 RCL 09
529 /
530 -4182
531 /
532 E↑X
533 -
534 RCL 60
535 RCL 57
536 -
537 *
538 RCL 57
539 +
540 RTN
541♦LBL "LAP"
542 1
543 RCL 53
544 RCL 01
545 RCL 63
546 +
547 /
548 +
549 ST* 02
550 RCL 51
551 RCL 53
552 ST+ 01
553 CHS
554 Y↑X
555 RCL 02
556 *
557 1
558 X>Y?
559 X<>Y
560 STO 02
561 RTN
562♦LBL "MP"
563 RCL 52
564 1013
565 /
566 RCL 06
567 R-D
568 3.885
569 +
570 -1.253
571 Y↑X
572 .15
573 *
574 RCL 06
575 SIN
576 +
577 /
578 STO 11
579 RTN
580♦LBL "W"
581 1.004
582 STO 12
583 RCL 01
584 RCL 63
585 +
586 1/X
587 STO 13
588 RCL 51
589 RCL 01
590 Y↑X
591 RCL 02
592 *
593 ST* 13
594 LN
595 RCL 51
596 LN
597 /
598♦LBL 12
599 RCL 63
600 +
```

Figure IV.5. (continued)

```
601 RCL 13
602 *
603 LN
604 RCL 51
605 LN
606 /
607 ISG 12
608 GTO 12
609 .0614
610 *
611 .110
612 +
613 E↑X
614 .85
615 *
616 STO 10
617 RTN
618♦LBL "a1"
619 1
620 .134
621 RCL 10
622 *
623 .465
624 +
625 CHS
626 -.880
627 RCL 11
628 *
629 E↑X
630 .171
631 *
632 .129
633 +
634 *
635 RCL 11
636 *
637 E↑X
638 -
639 STO 12
640 RTN
641♦LBL "a2"
642 .134
643 RCL 10
644 *
645 .465
646 +
647 CHS
648 -.721
649 RCL 11
650 *
651 E↑X
652 .421
653 *
654 .179
655 +
656 *
657 RCL 11
658 *
659 E↑X
660 STO 13
661 RTN
662♦LBL "eNZ"
663 RCL 12
664 RCL 07
665 -
666 2
667 /
668 RCL 13
669 +
670 1
671 RCL 12
672 RCL 07
673 +
674 2
675 /
676 RCL 08
677 *
678 -
679 /
680 RTN
681♦LBL "eCL"
682 RCL 04
683 2
684 3
685 /
686 Y↑X
687 .78
688 *
689 .22
690 +
691 RTN
692♦LBL "RT"
693 -.45
694 RCL 04
695 -.1593
696 *
697 +
698 RCL 04
699 X↑2
700 .5986
701 *
702 +
703 1
704 RCL 04
705 -.9862
706 *
707 +
708 /
709 RCL 06
710 R-D
711 X<>Y
712 Y↑X
713 STO 00
714 .33
715 RCL 04
716 1.8343
717 *
718 +
719 RCL 04
720 X↑2
721 -2.1528
722 *
723 +
724 1
725 RCL 04
726 -.9902
727 *
728 +
729 /
730 RCL 00
731 *
732 RTN
733♦LBL "ABCD"
734 5.40 E-8
735 STO 41
736 1.40
737 RCL 03
738 *
739 3.75
740 +
741 1 E-03
742 *
743 RCL 52
744 *
745 1.65
746 +
747 STO 42
748 15.0
749 RCL 03
750 *
```

Figure IV.5. (continued)

```
40.0
+
STO 43
RCL 51
RCL 01
Y↑X
RCL 02
*
SQRT
.706
*
3.35
+
1
RCL 55
-
*
1
RCL 04
-
1.2
Y↑X
.17
*
1
+
*
5.24
RCL 55
*
+
RCL 01
RCL 63
+
X↑2
X↑2
*
1 E-8
*
1.40
RCL 03
*
3.75
+
1 E-03
*
RCL 01
*
RCL 52
*
+
1.65
RCL 56
*
+
15.0
RCL 03
*
40.0
+
RCL 02
*
RCL 51
RCL 01
Y↑X
*
+
9805
RCL 09
*
RCL 50
/
RCL 54
*
+
1
RCL 55
-
RCL 05
*
+
STO 44
RTN
♦LBL 88
"⊢= "
ARCL X
AVIEW
RTN
END
```

Figure IV.5. (concluded)

The HP-41C version of the instream water temperature heat transport model is the fifth of the desk-top calculator stand-alone programs. The register utilization is given in Table IV.8 and the source coding is shown in Figure IV.6.

This program allows flexibility in analyzing various meteorology, stream geometry, and hydrology conditions at any point downstream from a known starting water temperature. It uses input from the previous programs and can duplicate the math model algorithms of the FORTRAN 77 program.

Table IV.8. Instream water temperature heat transport model.

Size 047

Reg.	Use	Reg.	Use
00	H_{sg}	01	S/S_o
02	S_h	03	T_a
04	W_a	05	R_h
06	P_a	07	S_f
08	1.0640	09	W,B
10	1-a',D	11	a",C
12	Q_o	13	q_ℓ
14	T_y,T_ℓ	15	$\overline{B}$
16	S_o	17	$f(T_e),d_x$
18	$f'(T_e),t_x$	19	n
20	x_o	21	X loop
22	a,T_e'	23	T,T_e,b
24	R	25	$\overline{\alpha}$
26	Z_o,Z_a	27	$Z_a,T_{ao}-T_a,\Delta\overline{T}_{ax}$
28	H_{sx}	29	m_p
30	d	31	R_g

Table IV.8. (concluded)

Reg.	Use	Reg.	Use
32	$1-R_t$	33	T_{od}
34	T_{ed}	35	K_{1d}
36	K_{2d}	37	T_{wd}
38	T_{ox}	39	T_{ex}
40	K_{1x}	41	T_{wx}
42	T_d loop, Q_B	43	T_B
44	Q_T	45	T_T
46	273.16		

Flag	Use	Flag clear	Flag set
00	T_x/T_n?	no	yes
01	$\Sigma H_i/f(T_w)$?	Component heat flux (ΣH_i)	coef. (A,B,C,D) for $f(T_w)$
02	X?	loop	single
03	$q_\ell<0$?	no	yes
04	$q_\ell=0$?	no	yes
05	$q_\ell>0$?	no	yes
06	not used	--	--
07	--	$X \neq X$ start	X=X start
08	--	compute $T_e, K_1, \Sigma H_i$	compute new T_e and K_1 for Q_o, no ΣH_i

This program requires nine magnetic cards.

```
01♦LBL "WATRAH"
02 "NO"
03 ASTO Y
04 "DIURNAL FLUCTUA"
05 "├TIONS?"
06 AVIEW
07 SF 00
08 AON
09 "R/S=YES"
10 AVIEW
11 "NO=NO"
12 PROMPT
13 ASTO X
14 AOFF
15 X=Y?
16 CF 00
17 ADV
18 CF 29
19 RAD
20♦LBL "MTRLGY"
21 FIX 0
22 CLRG
23 273.16
24 STO 46
25 ADV
26 "MET. STA. DATA"
27 AVIEW
28 "Z0:M=?"
29 PROMPT
30 STO 26
31 "TY:C=?"
32 PROMPT
33 STO 14
34 "TA:C=?"
35 PROMPT
36 STO 03
37 "WA:M/S=?"
38 PROMPT
39 STO 04
40 "RH:D=?"
41 PROMPT
42 STO 05
43 "HSX:J/M2/S=?"
44 PROMPT
45 STO 28
46 "a:RAD=?"
47 PROMPT
48 STO 25
49 "d:D=?"
50 PROMPT
51 STO 30
52 "RG:D=?"
53 PROMPT
54 STO 31
55 "S/S0:D=?"
56 PROMPT
57 STO 01
58 FC? 00
59 GTO 00
60 "S0:HR=?"
61 PROMPT
62 STO 16
63♦LBL 00
64 1013
65 STO 06
66 RCL 26
67 XEQ 16
68 ST* 06
69 RCL 25
70 R-D
71 3.885
72 +
73 -1.253
74 Y↑X
75 .15
76 *
77 RCL 25
78 SIN
79 +
80 /
81 STO 29
82 -.45
83 RCL 01
84 .1593
85 *
86 -
87 RCL 01
88 X↑2
89 .5986
90 *
91 +
92 1
93 RCL 01
94 .9862
95 *
96 -
97 /
98 RCL 25
99 R-D
100 X<>Y
101 Y↑X
102 STO 32
103 .33
104 RCL 01
105 1.8343
106 *
107 +
108 RCL 01
109 X↑2
110 2.1528
111 *
112 -
113 1
114 RCL 01
115 .9902
116 *
117 -
118 /
119 ST* 32
120 1
121 RCL 32
122 .99
123 X<=Y?
124 X<>Y
125 RDN
126 -
127 STO 32
128♦LBL "STRM"
129 1.064
130 STO 08
131 FIX 0
132 ADV
133 "STREAM DATA"
134 AVIEW
135 "ZA:M=?"
136 PROMPT
137 STO 27
138 "B :M=?"
139 PROMPT
140 STO 15
141 "SH:D=?"
142 PROMPT
143 STO 02
144 "SF:M/M=?"
145 PROMPT
146 STO 07
147 FC? 00
148 GTO 00
149 "N: =?"
150 PROMPT
```

Figure IV.6. HP-41C source code listing for the heat transport model.

```
151 STO 19
152♦LBL 00
153 RCL 26
154 XEQ 16
155 ST/ 06
156 ST/ 29
157 RCL 27
158 XEQ 16
159 ST* 06
160 ST* 29
161 RCL 26
162 RCL 27
163 STO 26
164 -
165 .00656
166 *
167 ST+ 14
168 STO 27
169 XEQ 13
170 1.004
171 STO 42
172 RCL 08
173 RCL 03
174 Y↑X
175 RCL 05
176 *
177 STO Y
178 RCL 03
179 RCL 46
180 +
181 /
182 STO Z
183 X<>Y
184 LN
185 RCL 08
186 LN
187 /
188♦LBL 42
189 RCL 46
190 +
191 RCL T
192 *
193 LN
194 RCL 08
195 LN
196 /
197 ISG 42
198 GTO 42
199 .0614
200 *
201 .110
202 +
203 E↑X
204 .85
205 *
206 .134
207 *
208 .465
209 +
210 CHS
211 STO 09
212 -.880
213 RCL 29
214 *
215 E↑X
216 .171
217 *
218 .129
219 +
220 *
221 RCL 29
222 *
223 E↑X
224 1
225 X<>Y
226 -
227 STO 10
228 -.721
229 RCL 29
230 *
231 E↑X
232 .421
233 *
234 .179
235 +
236 RCL 29
237 *
238 RCL 09
239 *
240 E↑X
241 STO 11
242 RCL 10
243 RCL 30
244 -
245 2
246 /
247 +
248 1
249 RCL 10
250 RCL 30
251 +
252 2
253 /
254 RCL 31
255 *
256 -
257 /
258 RCL 01
259 2
260 3
261 /
262 Y↑X
263 .78
264 *
265 .22
266 +
267 *
268 RCL 28
269 *
270 STO 00
271 CF 06
272 GTO 00
273♦LBL 16
274 .0065
275 *
276 288
277 X<>Y
278 -
279 288
280 /
281 5.256
282 Y↑X
283 RTN
284♦LBL "DSCHRG"
285 ADV
286 SF 06
287♦LBL 00
288 FIX 0
289 ADV
290 "DISCHARGE DATA"
291 AVIEW
292 "Q0:CMS=?"
293 PROMPT
294 X=0?
295 1 E-9
296 STO 12
297 "QL:CMS/KM=?"
298 PROMPT
299 STO 13
300 CF 03
```

Figure IV.6. (continued)

```
301 X<0?
302 SF 03
303 CF 04
304 X=0?
305 SF 04
306 CF 05
307 X>0?
308 SF 05
309 SF 01
310 XEQ 09
311 20
312 STO 23
313♦LBL 14
314 XEQ 11
315 ST- 23
316 ABS
317 1 E-7
318 X<=Y?
319 GTO 14
320 RCL 23
321 STO 34
322 RCL 18
323 STO 35
324 ADV
325 "OUTPUT"
326 AVIEW
327 FIX 2
328 "TE ="
329 ARCL 34
330 "├ C"
331 AVIEW
332 "K1 ="
333 ARCL 35
334 "├ J/M2/S/C"
335 AVIEW
336 FS? 06
337 GTO 00
338 ADV
339 CF 01
340 "HEAT FLUX:J/M2/"
341 "├S"
342 AVIEW
343 XEQ 09
344♦LBL 00
345 FC? 00
346 GTO 07
347 6.64
348 -880 E-6
349 RCL 28
350 *
351 +
352 -5.27
353 RCL 05
354 *
355 +
356 4.86
357 RCL 01
358 *
359 +
360 .3125
361 *
362 STO 27
363 XEQ 13
364 24
365 RCL 16
366 /
367 ST* 00
368 SF 01
369 XEQ 09
370♦LBL 17
371 XEQ 11
372 ST- 23
373 ABS
374 1 E-7
375 X<=Y?
376 GTO 17
377 RCL 23
378 STO 39
379 RCL 18
380 STO 40
381 RCL 27
382 CHS
383 STO 27
384 XEQ 13
385 RCL 16
386 24
387 /
388 ST* 00
389 GTO 07
390♦LBL 13
391 RCL 27
392 RCL 03
393 RCL 46
394 +
395 /
396 1
397 +
398 RCL 08
399 RCL 27
400 Y↑X
401 /
402 RCL 05
403 *
404 1
405 X>Y?
406 X<>Y
407 STO 05
408 RCL 27
409 ST+ 03
410 RTN
411♦LBL 07
412 ADV
413 BEEP
414 "INPUT"
415 AVIEW
416 FIX 0
417 "T0:C=?"
418 PROMPT
419 STO 33
420 STO 23
421 "X:KM=?"
422 PROMPT
423 STO 21
424 CF 02
425 1 E3
426 *
427 FRC
428 X=0?
429 SF 02
430 XEQ 12
431 SF 07
432 ADV
433 "OUTPUT"
434 AVIEW
435 FIX 3
436 "K2 ="
437 ARCL 36
438 "├ J/M2/S/C/C"
439 AVIEW
440 ADV
441 RCL 16
442 1.8
443 *
444 STO 18
445♦LBL 06
446 FIX 0
447 FS? 02
448 FIX 2
449 RCL 21
450 FC? 02
```

Figure IV.6. (continued)

```
451 INT
452 "X  ="
453 ARCL X
454 "├ KM"
455 AVIEW
456 RCL 13
457 *
458 RCL 12
459 +
460 RCL 15
461 /
462 FIX 4
463 "Q/B="
464 ARCL X
465 "├ CMS/M"
466 AVIEW
467 RCL 21
468 FC? 02
469 INT
470 X≠0?
471 GTO 00
472 RCL 33
473 STO 37
474 GTO 18
475♦LBL 00
476 CF 07
477 STO 20
478 RCL 35
479 RCL 15
480 *
481 4182
482 /
483 RCL 13
484 +
485 STO 23
486 FS? 03
487 GTO 03
488 FS? 04
489 GTO 04
490 FS? 05
491 GTO 05
492♦LBL 03
493 RCL 13
494 RCL 20
495 *
496 RCL 12
497 /
498 1
499 +
500 0
501 X<=Y?
502 X<>Y
503 RCL 13
504 RCL 23
505 -
506 RCL 13
507 /
508 Y↑X
509 RCL 34
510 GTO 00
511♦LBL 04
512 RCL 23
513 RCL 20
514 *
515 RCL 12
516 /
517 CHS
518 E↑X
519 RCL 34
520 GTO 00
521♦LBL 05
522 RCL 13
523 RCL 20
524 *
525 RCL 12
526 /
527 1
528 +
529 RCL 23
530 RCL 13
531 /
532 CHS
533 Y↑X
534 RCL 23
535 RCL 13
536 -
537 RCL 34
538 *
539 RCL 13
540 RCL 14
541 *
542 +
543 RCL 23
544 /
545♦LBL 00
546 STO 22
547 X<>Y
548 STO 24
549 RCL 22
550 RCL 33
551 -
552 STO 23
553 *
554 1
555 RCL 24
556 -
557 RCL 23
558 *
559 RCL 36
560 *
561 RCL 35
562 /
563 1
564 +
565 /
566 RCL 22
567 X<>Y
568 -
569 STO 37
570♦LBL 18
571 FC? 00
572 GTO 19
573 RCL 21
574 FC? 02
575 INT
576 RCL 13
577 RCL 20
578 *
579 RCL 12
580 +
581 RCL 15
582 /
583 RCL 19
584 *
585 RCL 07
586 SQRT
587 /
588 .6
589 Y↑X
590 STO 17
591 RCL 18
592 RCL 35
593 *
594 4182
595 /
596 RCL 17
597 /
598 E↑X
599 RCL 37
600 RCL 34
```

Figure IV.6. (continued)

```
601 -
602 *
603 RCL 34
604 +
605 STO 38
606 RCL 40
607 RCL 18
608 *
609 4182
610 /
611 RCL 17
612 /
613 CHS
614 E↑X
615 RCL 38
616 RCL 39
617 -
618 *
619 RCL 39
620 +
621 STO 41
622♦LBL 19
623 FIX 2
624 RCL 37
625 "TW ="
626 XEQ 08
627 FC? 00
628 GTO 00
629 RCL 41
630 "TX ="
631 XEQ 08
632 2
633 RCL 37
634 *
635 RCL 41
636 -
637 "TN ="
638 XEQ 08
639♦LBL 00
640 ADV
641 FS? 02
642 GTO 07
643 ISG 21
644 GTO 06
645 GTO 07
646♦LBL 08
647 0
648 X>Y?
649 X<>Y
650 RDN
651 ARCL X
652 AVIEW
653 RTN
654♦LBL 09
655 1.064
656 STO 08
657 RCL 03
658 Y↑X
659 RCL 05
660 *
661 SQRT
662 .706
663 *
664 3.36
665 +
666 1 E-8
667 *
668 1
669 RCL 02
670 -
671 *
672 1
673 RCL 01
674 -
675 1.2
676 Y↑X
677 .17
678 *
679 1
680 +
681 *
682 RCL 03
683 RCL 46
684 +
685 X↑2
686 X↑2
687 *
688 STO 10
689 FS? 01
690 GTO 00
691 "HA ="
692 ARCL X
693 AVIEW
694♦LBL 00
695 14 E-4
696 RCL 04
697 *
698 375 E-5
699 +
700 RCL 06
701 *
702 STO 09
703 RCL 03
704 FS? 01
705 GTO 00
706 RCL 23
707 -
708♦LBL 00
709 *
710 ST+ 10
711 FS? 01
712 GTO 00
713 "HC ="
714 ARCL X
715 AVIEW
716♦LBL 00
717 1.65
718 ST+ 09
719 RCL 14
720 FS? 01
721 GTO 00
722 RCL 23
723 -
724♦LBL 00
725 *
726 ST+ 10
727 FS? 01
728 GTO 00
729 "HD ="
730 ARCL X
731 AVIEW
732♦LBL 00
733 RCL 08
734 RCL 03
735 Y↑X
736 RCL 05
737 *
738 FS? 01
739 GTO 00
740 RCL 08
741 RCL 23
742 Y↑X
743 -
744♦LBL 00
745 15
746 RCL 04
747 *
748 40
749 +
750 STO 11
```

Figure IV.6. (continued)

```
751 *
752 ST+ 10
753 FS? 01
754 GTO 00
755 "HE ="
756 ARCL X
757 AVIEW
758+LBL 00
759 RCL 12
760 RCL 15
761 /
762 RCL 07
763 *
764 9805
765 *
766 ST+ 10
767 FS? 01
768 GTO 00
769 "HF ="
770 ARCL X
771 AVIEW
772+LBL 00
773 RCL 00
774 1
775 RCL 02
776 -
777 *
778 RCL 32
779 *
780 ST+ 10
781 FS? 01
782 GTO 00
783 "HS ="
784 ARCL X
785 AVIEW
786+LBL 00
787 RCL 03
788 RCL 46
789 +
790 X↑2
791 X↑2
792 RCL 02
793 *
794 5.24 E-8
795 *
796 ST+ 10
797 FS? 01
798 RTN
799 "HV ="
800 ARCL X
801 AVIEW
802+LBL 10
803 RCL 23
804 RCL 46
805 +
806 X↑2
807 X↑2
808 54 E-9
809 *
810 FS? 01
811 RTN
812 CHS
813 "HW ="
814 ARCL X
815 AVIEW
816+LBL 00
817 RCL 00
818 "HSG="
819 ARCL X
820 AVIEW
821 RTN
822+LBL 11
823 XEQ 10
824 RCL 23
825 RCL 09
826 *
827 +
828 RCL 08
829 RCL 23
830 Y↑X
831 RCL 11
832 *
833 +
834 RCL 10
835 -
836 STO 17
837 XEQ 10
838 RCL 23
839 RCL 46
840 +
841 /
842 4
843 *
844 RCL 09
845 +
846 RCL 08
847 RCL 23
848 Y↑X
849 RCL 08
850 LN
851 *
852 RCL 11
853 *
854 +
855 STO 18
856 /
857 RTN
858+LBL 12
859 SF 01
860 XEQ 09
861 XEQ 11
862 RCL 17
863 CHS
864 RCL 34
865 RCL 23
866 -
867 RCL 35
868 *
869 -
870 RCL 34
871 RCL 23
872 -
873 X↑2
874 /
875 STO 36
876 RTN
877+LBL "QMIX"
878 FIX 0
879 ADV
880 ADV
881 "QB:CMS=?"
882 PROMPT
883 STO 42
884 "TB:C=?"
885 PROMPT
886 STO 43
887 "QT:CMS=?"
888 PROMPT
889 STO 44
890 "TT:C=?"
891 PROMPT
892 STO 45
893 RCL 42
894 RCL 43
895 *
896 RCL 44
897 RCL 45
898 *
899 +
900 RCL 42
```

Figure IV.6. (continued)

```
901 RCL 44
902 +
903 FIX 3
904 ADV
905 "QJ:CMS="
906 ARCL X
907 AVIEW
908 /
909 FIX 2
910 "TJ:C="
911 ARCL X
912 AVIEW
913 GTO "QMIX"
914 END
```

Figure IV.6. (concluded)

BASIC VERSION

Introduction

Figure IV.7 contains the source code listing for the BASIC program. This code is written for standard Microsoft BASIC. Program changes would be necessary to run it under many other versions of BASIC. The program contains a self-test switch so that the results can be verified.

Source Code

```
 1Ø REM PROGRAM TEMPMOD, VERSION 1.1
 2Ø REM THIS PROGRAM IS AN ADAPTATION OF A FORTRAN MODEL TO CALCULATE
 3Ø REM THE TEMPERATURE OF A STREAM AT A DISTANCE DOWNSTREAM GIVEN THE
 4Ø REM ATTRIBUTES OF CLIMATE AND HYDROLOGY
 5Ø REM
 6Ø REM ORIGINAL PROGRAM WRITTEN BY FRED THEURER, SOIL CONSERVATION SERVICE
 7Ø REM ADAPTATION FOR MICROSOFT BASIC BY JOHN BARTHOLOW, INSTREAM FLOW AND
    AQUATIC
 8Ø REM   SYSTEMS GROUP, OCTOBER 1983
 9Ø REM
1ØØ PRINT "TEMPMOD VERSION 1.1"
11Ø DEBUG = Ø
12Ø REM CONVERSION FACTORS THAT ARE NICE TO KNOW
13Ø REM      FEET * Ø.3Ø48 = METERS
14Ø REM              MILES * 1.6Ø9 = KILOMETERS
15Ø REM              CFS * Ø.Ø2832 = CMS
16Ø REM              5/9 (FAHRENHEIT - 32) = CELSIUS
17Ø REM              MILES/HR. * Ø.447 = METERS/SEC.
18Ø REM CONSTANT INITIALIZATION
19Ø TABSØ=273.16    'TEMPERATURE AT ABSOLUTE ZERO
2ØØ RMIN=.ØØØØØ1     'MINIMUM ABSOLUTE REAL VALUE
21Ø EXPMAX = LOG(RMIN)              'MAXIMUM EXPONENT ALLOWED
22Ø VAPRS=1.Ø64'VAPOR PRESSURE
23Ø ALVPRS = LOG(VAPRS)
24Ø KNTMX=2Ø        'MAXIMUM NUMBER OF ITERATIONS IN SOLUTION TECHNIQUE
```

Figure IV.7. BASIC source code listing.

```
25Ø TOLRN = .ØØØ1

26Ø RHOCP=4.182E+Ø6  'DENSITY OF WATER * SPECIFIC HEAT

27Ø QMIN=.ØØØØØ1              'MINIMUM FLOW ALLOWED

28Ø EFA = 4Ø!                 'REGRESSION COEFFICIENT A

29Ø EFB=15!  'REGRESSION COEFFICIENT B

3ØØ EFC=Ø!            'REGRESSION COEFFICIENT C

31Ø BOWENR=.ØØØ619    'BOWEN RATIO - DEALS WITH CONVECTION & CIRCULATION

32Ø AØ=6.64           'THESE DEAL WITH REGRESSION COEFFICIENTS TO CONVERT AVERAGE
    DAILY AIR TEMP TO MAX DAILY AIR TEMP

33Ø A1=-.ØØ14         '?

34Ø A2=-5.27          '?

35Ø A3=4.86           '?

36Ø REM *********************************************************************

37Ø REM

38Ø REM NOW GET MODEL INPUT

39Ø REM

4ØØ INPUT"How many kilometers downstream do you want to look";XD

41Ø REM ANSWER -1 FOR TESTING PURPOSES

42Ø REM ANSWERS SHOULD BE:   TE = -6.Ø39429         AK1 = 14.95802

43Ø REM                              AK2D = -.1416844      TE = 3.756288

44Ø REM                              AK1 = 17.92419         MAX = 12.45Ø57

45Ø REM                              AVG = 11.75968         MIN = 11.Ø688

46Ø IF XD>Ø THEN 54Ø

47Ø DEBUG = Ø

48Ø RESTORE

49Ø DATA 11.,.Ø6,5.,.ØØØØ49,15.,-1Ø.,.3,2.,.5,117.76,.1,1Ø.4,.Ø35,.ØØ545
```

Figure IV.7. (continued)

```
500 DATA 945.22,2.,Ø.,15.,1.65,1.

510 READ  XD,QØ,TØ,QL,TL,TA,RH,WA,SØ,HSW,SH,DAYLIT,AN,SF,PA,AW,BW,TG,AKZ,DAM

520 PRINT XD,QØ,TØ,QL,TL,TA,RH,WA,SØ,HSW,SH,DAYLIT,AN,SF,PA,AW,BW,TG,AKZ,DAM

530 GOTO 8ØØ

54Ø INPUT"What is the discharge at the upstream point in cubic meters per
    second";QØ

55Ø INPUT"What is the initial temperature of the water in degrees Celsius";TØ

56Ø INPUT"What is the total flow at the downstream point at this flow";TEMP

57Ø QL=(TEMP-QØ)/XD/1ØØØ!            'LATERAL DISCHARGE IN CM/S/M

58Ø INPUT"What temperature is the lateral inflow in degrees Celsius";TL

59Ø INPUT"What is the air temperature in degrees Celsius";TA

6ØØ INPUT"What is the relative humidity as a decimal fraction";RH

61Ø INPUT"What is the windspeed in meters per second";WA

62Ø INPUT"What is the percent possible sunshine from your LCD as a decimal
    fraction";SØ

63Ø PRINT "See the manual on this next one ..."

64Ø INPUT"How much solar radiation is penetrating the water in
    Joules/sq.m./sec?";HSW

65Ø INPUT"What percent shading of the stream is there expressed as a decimal";SH

66Ø INPUT"How many hours of daylight are there";DAYLIT

67Ø INPUT"What is the Manning's N factor (suggested value = .Ø35)";AN

68Ø INPUT"What is the elevation in meters of the upstream point";TEMP1

69Ø INPUT"What is the elevation in meters of the downstream point";TEMP2

7ØØ SF=(TEMP1-TEMP2)/XD/1ØØØ!              'FRICTION SLOPE - DECIMAL

71Ø PA = (TEMP1 + TEMP2) / 2

72Ø PA = 1Ø13! * ((288! - .ØØ65 * PA) / 288!) ↑ 5.256

73Ø PRINT "For the equation WIDTH = A * Q ** B :"
```

Figure IV.7. (continued)

```
740 INPUT"What is the A term (A = width, if width is constant)";AW
750 INPUT"What is the B term (B = 0     , if width is constant)";BW
760 PRINT"What is the ground temperature in degrees Celsius"
770 INPUT"We suggest mean annual air temperature";TG
780 INPUT"What is the streambed thermal gradient (suggest 1.65)";AKZ
790 INPUT"Enter 1 for dam at upstream, 0 for no dam";DAM
800 REM
810 REM BEGIN THE MAIN PROGRAM
820 IF Q0 < QMIN THEN Q0 = QMIN
830 REM CALCULATE THE EQULIBRIUM PARAMETERS
840 TWD = T0
850 GOSUB 1120
860 REM CALCULATE THE AVERAGE DAILY WATER TEMP
870 XD1000 = XD * 1000!
880 DELX = XD1000
890 BAVG = AW * (Q0 + ((QL * XD1000) / 2!)) ↑ BW
900 TE = TED
910 AK1 = AK1D
920 AK2 = AK2D
930 GOSUB 2090
940 TWD = TWAVG
950 REM CALCULATE THE MAXIMUM DAILY WATER TEMP
960 DLIT = DAYLIT
970 Q0 = Q0 + (QL * XD1000)
980 GOSUB 2530
990 TWX = TWMAX
```

Figure IV.7. (continued)

```
1ØØØ REM CALCULATE THE MINIMUM AS THE DIFFERENCE
1Ø1Ø TWN=TWD-(TWX-TWD)
1Ø2Ø IF TWN < Ø! THEN TWN = Ø!
1Ø3Ø REM PRINT THE RESULTS
1Ø4Ø PRINT "The maximum daily water temperature is ";TWX;" degrees Celsius."
1Ø5Ø PRINT "The average daily water temperature is ";TWD;" degrees Celsius."
1Ø6Ø PRINT "The minimum daily water temperature is ";TWN;" degrees Celsius."
1Ø7Ø PRINT
1Ø8Ø INPUT"Enter new upstream discharge";QØ
1Ø9Ø IF QØ < Ø! THEN 4ØØ
11ØØ GOTO 81Ø
111Ø REM ********************************************************************
112Ø REM SUBROUTINE TO DETERMINE THE AVERAGE AND MAXIMUM DAILY WATER TEMP
113Ø REM PARAMETERS
114Ø IF DEBUG THEN PRINT "EQUILIB"
115Ø REM
116Ø REM DETERMINE EVAPORATION FACTOR
117Ø EVFCTR = EFA + (EFB * WA) + (EFC * SQR(WA))
118Ø IF EVFCTR <Ø! THEN EVFCTR = Ø!
119Ø CRFCTR = BOWENR / 6.6
12ØØ REM
121Ø REM AVERAGE DAILY CONDITIONS
122Ø CL = (1! - SØ) ↑ .6
123Ø BAVG = AW * (QØ ↑ BW)
124Ø VPAIR = VAPRS ↑ TA
```

Figure IV.7. (continued)

```
1250 TAABS = TA + TABS0

1260 REM

1270 REM HEAT FLUX COMPONENTS

1280 HA = ((3.36E-08 + 7.06E-09 * SQR(RH * VPAIR)) * (1! - SH) * (1! + (.17 *
     (CL ↑ 2)))) * (TAABS ↑ 4)

1290 HF = 9805! * (Q0 / BAVG) * SF

1300 HS = (1! - SH) * HSW

1310 HV = 5.24E-08 * SH * (TAABS ↑ 4)

1320 IF DEBUG THEN PRINT HA,HF,HS,HV

1330 REM

1340 REM DETERMINE EQULIBRIUM COEFFICIENTS

1350 A = 5.4E-08

1360 B = (CRFCTR * EVFCTR * PA) + AKZ

1370 C = EVFCTR

1380 D = (HA + HF + HS + HV) + (CRFCTR * EVFCTR * PA * TA) + (EVFCTR * RH *
     VPAIR) + (TG * AKZ)

1390 REM

1400 REM DETERMINE EQULIBRIUM TEMPERATURE & 1st ORDER THERMAL EXCHANGE COEF.

1410 TE=TA

1420 GOSUB 1830

1430 REM HANDLE PARAMETER TRANSFER

1440 TED = TE

1450 AK1D = AK1

1460 REM

1470 REM DETERMINE 2nd ORDER THERMAL EXCHANGE COEFFICIENT

1480 HNET = (A * ((TWD + TABS0) ↑ 4)) + (B * TWD) + (C * (VAPRS ↑ TWD)) - D
```

Figure IV.7. (continued)

```
1490 DELT = TWD - TED
1500 IF (ABS(DELT) >= RMIN) GOTO 1530
1510 AK2D = 0!
1520 GOTO 1550
1530 AK2D = ((DELT * AK1D) - HNET) / (DELT ↑ 2)
1540 IF DEBUG THEN PRINT "AK2D = ";AK2D
1550 REM
1560 REM CHECK FOR MAXIMUM DAILY WATER TEMPERATURE REQUEST
1570 IF AN<> 0! GOTO 1610
1580 TEX = 0!
1590 AK1X = 0!
1600 GOTO 1810
1610 IF DAYLIT > 0! GOTO 1640
1620 HS = 0!
1630 GOTO 1650
1640 HS = HS * (24! / DAYLIT)
1650 DELTAX = .3125 * (A0 + (A1 * HSW) + (A2 * RH) + (A3 * S0))
1660 RHX = RH * ((VAPRS ↑ (-DELTAX)) * (1! + (DELTAX / TAABS)))
1670 IF RHX > .9999 THEN RHX = .9999
1680 TAX = TA + DELTAX
1690 TAXABS = TAX + TABS0
1700 VPAIR = VAPRS ↑ TAX
1710 HA = (3.36E-08 + 7.06E-09 * SQR(RHX * VPAIR)) * (1! -SH)
1720 HA = HA * (1! + (.17 * (CL ↑ 2))) * (TAXABS ↑ 4)
1730 HV = 5.24E-08 * SH * (TAXABS ↑ 4)
```

Figure IV.7. (continued)

```
1740 D = (HA + HF + HS + HV) + (CRFCTR * EVFCTR * PA * TAX)
1750 D = D + (EVFCTR * RHX * VPAIR) + (TG * AKZ)
1760 TE = TED + DELTAX
1770 GOSUB 1830
1780 REM HANDLE PARAMETER TRANSFER
1790 TEX = TE
1800 AK1X = AK1
1810 RETURN
1820 REM ***********************************************************************
1830 REM SUBROUTINE TO DETERMINE THE EQULIBRIUM WATER TEMPERATURE FROM THE
1840 REM HEAT FLUX EQUATION USING A NEWTON SOLUTION TECHNIQUE;
1850 REM AND TO DETERMINE THE 1st THERMAL EXCHANGE COEFFICIENT.
1860 REM
1870 REM IF DEBUG THEN PRINT "TEAK1"
1880 REM INITIALIZE ITERATION COUNTER & ARBITRARY CONSTANT
1890 KOUNT = 0
1900 CLOG = C * ALVPRS
1910 REM
1920 REM BEGIN NEWTON ITERATION SOLUTION FOR TE
1930 KOUNT = KOUNT + 1
1940 TEABS = TE + TABS0
1950 VPRSTE = VAPRS ^ TE
1960 FTE = (A * (TEABS ^ 4)) + (B * TE) + (C * VPRSTE) - (D)
1970 FPTE = (4! * A * (TEABS ^ 3)) + (B) + (CLOG * VPRSTE)
1980 DELTE = FTE / FPTE
```

Figure IV.7. (continued)

```
1990 TE = TE - DELTE
2000 IF(((ABS(FTE)>TOLRN)OR(ABS(DELTE)>TOLRN))AND(KOUNT<KNTMX))GOTO 1930
2010 PRINT "TE = ";TE
2020 REM
2030 REM DETERMINE 1st THERMAL EXCHANGE COEFFICIENT
2040 AK1 = (4! * A * ((TE + TABS0) ↑ 3)) + (B) + (CLOG * (VAPRS ↑ TE))
2050 IF DEBUG THEN PRINT "AK1 = ";AK1
2060 REM
2070 RETURN
2080 REM ********************************************************************
2090 REM SUBROUTINE TO PREDICT THE AVERAGE DAILY WATER TEMPERATURE USING A
2100 REM SECOND-ORDER CLOSED-FORM SOLUTION TO THE STEADY-STATE HEAT TRANSPORT
2110 REM EQUATION
2120 REM
2130 IF DEBUG THEN PRINT "TWAVG"
2140 REM DETERMINE EQUATION PARAMETERS
2150 B = QL + ((AK1 * BAVG) / RHOCP)
2160 R = 1! + ((QL * DELX) / Q0)
2170 IF R < RMIN THEN R = RMIN
2180 REM
2190 REM CHECK FOR SIGN OF LATERAL FLOW TERM
2200 IF ABS(1!-R)>= RMIN GOTO 2300
2210 REM
2220 REM ZERO LATERAL FLOW
2230 TEP = TE
```

Figure IV.7. (continued)

```
22400 REXP = -(B * DELX) / Q0
22500 IF REXP < EXPMAX THEN REXP = EXPMAX
22600 R = EXP(REXP)
22700 GOTO 24400
22800 REM
22900 REM LOSING STREAM
23000 IF QL>= 0! GOTO 23800
23100 TEP = TE
23200 REXP = (QL - B) / QL
23300 IF REXP > (-6! / LOG(R)) THEN REXP = -6! / LOG(R)
23400 R = R ↑ REXP
23500 GOTO 24400
23600 REM
23700 REM GAINING STREAM
23800 TEP = ((QL * TL) + (((AK1 * BAVG) / RHOCP) * TE)) / B
23900 REXP = -B / QL
24000 IF REXP < (-6! / LOG(R)) THEN REXP = -6! / LOG(R)
24100 R = R ↑ REXP
24200 REM
24300 REM END LATERAL FLOW TERM LOGIC
24400 REM
24500 REM DETERMINE WATER TEMPERATURE
24600 DELT = TEP - T0
24700 TW = TEP - (DELT * (R / (1! + (AK2 / AK1) * DELT * (1! - R))))
24800 IF TW 2 0! THEN TW = 0!
```

Figure IV.7. (continued)

```
2490 TWAVG = TW
2500 REM
2510 RETURN
2520 REM ***********************************************************************
2530 REM SUBROUTINE TO PREDICT THE MAXIMUM DAILY WATER TEMPERATURE USING A
2540 REM FIRST ORDER CLOSED-FORM SOLUTION TO THE DYNAMIC-TEMPERATURE HEAT
2550 REM TRANSPORT EQUATION.
2560 REM
2570 IF DEBUG THEN PRINT "TWMAX"
2580 REM DETERMINE DEPTH OF FLOW
2590 DEPTH = (((Q0 * AN) / BAVG) / (SQR(SF))) ↑ .6
2600 REM
2610 REM DETERMINE TIME FROM SOLAR NOON TO SUNSET: TIME = 3600 * (DLIT / 2)
2620 TIME = DLIT * 1800!
2630 V = (Q0 + (QL * XD1000) / 2!) / BAVG / DEPTH
2640 TIME2 = XD1000 / V
2650 IF DAM AND (TIME2 < TIME) THEN TIME = TIME2
2660 REM
2670 REM DETERMINE DEPTH-TIME FACTOR
2680 FCTR = TIME / (RHOCP * DEPTH)
2690 REM
2700 REM DETERMINE SOLAR NOON WATER TEMPERATURE AT TIME-DISTANCE UPSTREAM
2710 T0X = TED - (TED - TWD) * EXP(AK1D * FCTR)
2720 REM
2730 REM DETERMINE MAXIMUM WATER TEMPERATURE AT SUNSET
```

Figure IV.7. (continued)

```
2740 TWX = TEX - (TEX - T0X) * EXP(-AK1X * FCTR)
2750 IF TWX < 0! THEN TWX = 0!
2760 TWMAX = TWX
2770 REM
2780 RETURN
2790 REM ******************************************************************
```

Figure IV.7. (concluded)

FORTRAN 77 SOLUTION TECHNIQUE

FORTRAN 77 Computer Program

A magnetic tape for version 1.0 of the instream water temperature model, dated May, 1984, is available through:

Instream Flow and Aquatic Systems Group
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
Creekside One Building
2627 Redwing Road
Fort Collins, CO 80526-2899

The source coding is written entirely in standard FORTRAN 77. It makes extensive use of CHARACTER strings, block IFS, PARAMETER statements, and direct access files. Therefore, the available compiler must support these features in order to use this solution technique. Some microcomputer software supports the necessary features; e.g., Intels' FORTRAN 86.

The magnetic tape contains the following five groupings of file data:

(1) User message--instructions to user on how to load the model;

(2) CYBER procedure--to execute the verification data set on a CYBER NOS 1.4 operating system;

(3) FORTRAN 77 source code--standard ANSI source code for the instream water temperature model computer program;

(4) Input verification data set--test data to check loading of the program on the user's system; and

(5) Output verification tables--to compare test output against a known output set.

Not all systems use the CYBER operating system. Therefore, the procedure in number (2) can only be used as a guide for non-CYBER systems.

Each of the source coding programs in (3) are well commented and some have extensive variable name lists. An attempt was made to keep variable names identical between all programs; therefore, the variable name lists in one program may serve for the other programs.

A key system design feature is the extensive use of files in lieu of large arrays. This feature, coupled with the standard FORTRAN 77 features, ensures portability between large mainframe computers and downward portability to some microcomputers.

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16. Abstract (Limit: 200 words)

This water temperature model is designed to predict instream water temperatures based on either historical or synthetic hydrological, meteorological, and stream geometry conditions The model is applicable to any size watershed or river basin.

The report has four sections:

Part I. Applications. This is an overview designed to explain the objective and scope of the model, discuss data sources and different solution techniques available, and provide illustrative examples of the use of the model.
Part II. Physical processes and math models. This part discusses the fundamental principles involved and corresponding math models, and is written for the hydrologist or hydraulic engineer.
Part III. User's manual. This section is for the technician who will actually be doing the calculations.
Part IV. Software support documentation. This part is written for the ADP/engineering staff responsible for supporting each solution technique, and provides a comprehensive program description for each solution technique.

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